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CUSTOMER PREMISE SERVICE STUDY FOR 30/20 GHZ SATELLITE SYSTEMS

FINAL REPORT

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16. Abstract

Satellite systems in which the space segment operates in the 30/20 GHz frequency band are defined and compared as to their potential for providing various types of communications services to customer premises and the economic and technical feasibility of doing so. Seven technical tasks were performed:

Task 1 - Market Postulation
Task 2 - Definition of the Ground Segment
Task 3 - Definition of the Space Segment
Task 4 - Definition of the Integrated Satellite System
Task 5 - Service Costs for Satellite Systems
Task 6 - Sensitivity Analysis
Task 7 - Critical Technology

Based on an analysis of previously developed market data, a sufficiently large market for services is projected so as to make the system economically viable. A large market, and hence a high capacity satellite system, is found to be necessary to minimize service costs, i.e., economy of scale is found to hold. The wide bandwidth expected to be available in the 30/20 GHz band, along with frequency reuse which further increases the effective system bandwidth, makes possible the high capacity system. Extensive ground networking is required in the most attractive systems to both connect users into the system and to interconnect earth stations to provide spatial diversity. Earth station spatial diversity is found to be a cost effective means of compensating the large fading encountered in the 30/20 GHz operating band.

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ADDENDUM A

AN APPLICATION OF SS-TDMA/FIXED BEAM SERVICE COSTING ALGORITHMS

ADDENDUM A

AN APPLICATION OF SS-TDMA/FIXED BEAM SERVICE COSTING ALGORITHMS

A detailed example of the use of the service costing algorithms is presented here to illustrate how the several algorithms are applied. The example is for the following system:

System	SS-TDMA/Fixed Beam
Number of Beams	100 Over CONUS
Peak Capacity	15 Gbps
Availability	99.9%
Earth Station Diversity	All CONUS Rain Tones
Earth Stations Antennas	7 Meter Diameter
Ground Networking	Microwave Radio - To Connect User Facilities to Earth Station - To Interconnect Earth Stations for Spatial Diversity Operation
Earth Station Life	5 Years
Space Segment Life	10 Years
Ground Networking Life	15 Years

The calculations are very tedious and involved if the variations between rain zones, variation in traffic density and possible variations in earth station size are taken into account. Consequently, to illustrate the procedure, the example is worked out under the conditions that the traffic is uniform across the CONUS, all earth stations are the same size, all carry the same amount of traffic and all have the same number of user facilities connected to them.

Service costs consist of the space segment costs plus the ground networking costs plus the earth station costs. These are worked out separately and then summed to show the total system costs. For convenience, traffic is considered in multiples of T1 rates, 1.544 Mbps.

A.1 GROUND NETWORKING COSTS

Table A-1 illustrates the calculation of the ground networking costs. It is based on the use of microwave radio for all ground networking, i.e., user facilities to the earth stations and between earth stations to provide for earth station spatial diversity operation.

Annotations included in the table show either how the table entry was derived, a location in the text of relevant data or the location of further explanation.

A.2 EARTH STATION COSTS

In Table A-2 an equation summarizing the earth station costing data is given along with values for the various terms the equation. Implicit in the burst rate value of 150 Mbps noted in the table is the assumption that the traffic is spread uniformly over the CONUS and all 3920/5 = 794 earth stations are identical. Practically there would be several earth station sizes, that is, over the CONUS earth stations of various capacities would be used to match the capacity to the specific local area requirements. That would lead to production requirements for the several earth station sizes. Based on the quantities, the "Quantity Factor" of Figure 3.5-3, reflecting the learning curve, could be applied. Because the earth stations are assumed to be all the same in the example, the learning curve data does not reflect the quantity buy cost reduction. If it did, a buy of 794 stations would result in a 30% decrease in costs.

A.3 SPACE SEGMENT COSTS

Space segment service costs are derived from the space segment initial investment and that is calculated from the spacecraft beginning of life weight. The BOL weight in turn is derived from the payload and electrical power subsystems weight.

Table A-3 summarizes the payload weight and power calculations. The power calculation gives 2815 watts for the payload power: at the 18.2 watts per pound assumed for the advanced technology EPS, the weight of that subsystem is 155 pounds. The EPS plus payload weight is 683 + 155 = 838 pounds. Adding 10% contingency gives 922 pounds. The payload plus EPS weight is taken as 45% of the satellite BOL weight, Section 4.2.5, which gives the satellite BOL weight as 2049 pounds.

From Figure 4.2-3 and associated text, this BOL weight is converted to an initial investment for the space segment. Using the equation

$$\ln R = 0.7625 \ln W + 4.936$$

where R = is the lump sum initial investment in millions of dollars and W is the BOL weight in kilopounds, the initial investment is found to be $240,600,000. The cost factor of 1.2, Sections 6.1 and 4.2.5, is used to convert the initial investment to annual charges, which are $288,700,000 per year.

The postulated system supports 7840 T1 links giving an average space segment annual cost of $36,800 per year per T1 link.

A.4 ANNUAL SERVICE COSTS FOR EXAMPLE SYSTEM

The annual service cost are the sum of the ground networking, earth station and space segment annual costs. From the previously derived data:

Ground Networking	$28,800
Earth Station	22,200
Space Segment	36,800
Total System	$87,800 Per T1 Link Per Year.

TABLE A-1: GROUND NETWORKING COSTS

GROUND NETWORKING		
PEAK DATA RATE PER AVERAGE FACILITY	2.87 Mbps	Weighted Average of Data in Table 3.6-4
NUMBER OF FACILITIES IN CONUS	3920	(.75)(15000 Mbps/2.87 Mbps per Facility); 75% TDMA Frame Efficiency; See Section 4.1.4, Discussion of Payload Implementation Concepts.
FACILITIES PER ES	5	Assumption
FACILITY DENSITY	0.072 Fac/km^2	Section 6.2
AVERAGE LENGTH OF LINK FACILITY TO ES (NETWORKING)	3.3 km	Section 6.2; $r_{ave} = \sqrt{(\text{Fac.}/\text{ES})/((2\pi)(\text{Fac. Density}))}$
AVERAGE LENGTH OF LINK ES TO ES (DIVERSITY)	9.3 km	Section 6.2; $d = 2\sqrt{2}\, r_{ave}$
NETWORKING LINKS/ES	5 - 2 T1	2.87 Mbps Requires 2 T1 Lines at 1.5 Mbps Each
EARTH STATION CAPACITY REQUIRED	14.35 Mbps	5 x 2.87 Mbps
NUMBER OF FACILITIES IN AVERAGE URBAN AREA	38	Table 3.6-4
NUMBER OF EARTH STATIONS IN AVERAGE URBAN AREA	8	38/5 Rounded Up = 8
DIVERSITY LINKS IN AVERAGE URBAN AREA	8 - 5 T1	Diversity Link Capacity required is half of ES capacity. Earth Stations are interconnected by the Ring Configuration of Figure 3.6-1.
COST OF NEWORKING		
NETWORKING LINES/AVERAGE AREA	$1,200,000	$15,000 x 10 x 8, See Section 3.6.3
NETWORK CONCENTRATION	$1,320,000	$5,000 x 8 + $16,000 x 10 x 8, See Section 3.6.3
COST OF DIVERSITY LINES	$1,378,000	See Section 3.6.3
TOTAL INVESTMENT COST	$3,898,000	
ANNUAL COST	$1,906,000	Cost Factor = 0.489, See Section 3.5.4
ANNUAL COST PER T1 LINE	23,826	Annual Cost ÷ 80 T1 Links in Area

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TABLE A-2: EARTH STATION COSTS

$C_{ES} = 3\ N_{T1} + BMC + ANT + C_{HPA/BR} + 85$ $1000 Table 3.5-2

ITEM	VALUE ($1,000)	COMMENT
CONSTANT	85	
$3N_{T1}$	30	10 T1 Links per ES from Ground Network Costing, Table A-1
BMC	60	Figure 3.5-4 SS-TDMA Burst Modem Costs
ANTENNA (7M Diameter)	180	Figure 3.5-2 Antenna Subsystem Costs v.s. Diameter
$C_{HPA/BR}$	16	$C_{HPA/BR} = 7.7\,[(BR/1.544)(P_{HPA/T1})]^{0.387}$, HPA Costs, See Section 3.5.2
		$P_{HPA/T1} = \mathrm{Log}^{-1}\,[0.1(\mathrm{EIRP}\ (\text{Table 3.2-19}) + 20 \log \alpha - 46.6 - 20 \log D)]$
		EIRP = 60.7 dB; Table 3.2-19
		α = 0.35 degrees; Figure 3.5-1
		$P_{HPA/T1} = 0.064$
		BR = Burst Rate = 15000 Mbps/100 Beam = 150 Mbps/Beam
C_{ES}	$371K	Earth Station Initial Investment
ANNUAL COST	$222K	Charge Factor = 0.599; Table 3.5-5 for 5 Year Life @ 20% ROI
ANNUAL COST PER T1	$22.2K	10 T1 Links per ES from Table A-1

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TABLE A-3: PAYLOAD WEIGHT AND POWER

Payload Weight = $47.6 + 5.01 \sqrt{N_B} + 13.38\ N_B + 0.026\ N_{ch} + 9.72 \times 10^{-4}\ (EIRP)(DR/N_B)(1/D)^2$ + Switch Weight; Table 4.2-14

ITEM	VALUE	COMMENT
CONSTANT	47.6	
$5.01\ /N_B$	50.1	N_B, Number of Beams, is 100 From Systems Definition
$13.38\ N_B$	133.8	
$0.206\ N_{ch}$	50.7	N_{ch}, Number of Channels, is 246 from Table 4.2-14
$(9.72 \times 10^{-4})(EIRP) \times (DR/N_B)(1/D^2)$	352.0	EIRP, From Table 4.2-17 is $10^{5.073}$ DR, Peak Aggregate Data Rate, is 15000 Mbps from System Definition D, Earth Station Antenna Diameter, is 7 Meters from System Definition
SWITCH WEIGHT	48.7	From Table 4.2-14
PAYLAOD WEIGHT	682.9 lbs	

Payload Power = $42.0 + 4.24\ N_B + 0.2\ N_{CH} + 5.73 \times 10^{-3}\ (EIRP)(DR/N_B)(1/D)^2$ + Switch Power; Table 4.2-14

CONSTANT	42.0	
$4.24\ N_B$	424.0	$N_B = 100$
$0.2\ N_{CH}$	44.4	$N_{CH} = 222$ For Computing Power
$5.73 \times 10^{-3}(EIRP) \times (DR/N_B)(1/D)^2$	2075.2	
SWITCH POWER	229.8	Table 4.2-14
PAYLOAD POWER	2815.4 Watts	

SECTION 1

INTRODUCTION

SECTION 1
INTRODUCTION

Seven technical tasks were carried out under the study and are reported here. These were:

Task 1 - Market Postulation

Task 2 - Definition of the CPS Ground Segment for the Satellite System

Task 3 - Definition of the Space Segment for the Satellite System

Task 4 - Definition of the Integrated Satellite System

Task 5 - Service Costs for the Integrated Satellite Systems

Task 6 - Sensitivity Analyses

Task 7 - Identification of Critical Technology

Through these tasks potential markets are defined in terms of aggregate traffic, types and number of users and required service offerings. This market data provides the basis for establishing space and ground segment requirements. Alternative means of satisfying these requirements are examined and compared in terms of service costs and from this comparison a recommended system defined. For that system the technology critical to its implementation is defined.

This introductory section summarizes the results of the tasks.

1.1 MARKET POSTULATION

The size and build-up of the aggregate traffic captured by the 30/20 GHz CPS system are important factors in the service costing and in the sizing of the space and ground segments. The data used is based on analyses of the traffic capture scenarios presented in the ITT Phase II study. In that study seven scenarios are considered. The first four scenarios are based on the 30/20 GHz system in combination with terrestrial or C-Band or Ku Band systems where no outage back up is provided. For the purpose of the present study these scenarios are taken as equivalent to a channel availability of 99.5%. In the other three scenarios backup to minimize outages is assumed and the overall availability is greater: 99.9% or more for the purposes of the present study. These availabilities determine the aggregate market for the CPS system.

For the low availability scenarios, the projected year 2000 peak traffic captured is about 4 Gbps. For the higher availability scenarios, the projected year 2000 peak traffic ranges from 15 Gbps to 33 Gbps. The year 1990 captured traffic, which is the initial system traffic, ranges from 0.25 Gbps to 3.4 Gbps. For costing purposes it is assumed that the year 1990 traffic is 10% of the year 2000 traffic and grows at 25% per year.

The rate at which the satellite capacity is filled is an important factor in the service costs. As an extreme example, it has been found that if a 100% use of the satellite capacity could be achieved at the beginning of service a 2:1 reduction of service cost could be realized. Thus a means of capturing traffic early in the system life is critically important in achieving competitive costs. This is particularly important for the CPS system since large systems yield lower costs.

A detailed breakdown of traffic classes show a large number of classes requiring data rates of 9.6 kbps or less. These have been classically supported by the TELCO networks. However, being pervasive classes, they are supported by the CPS system. These lower rate applications are multiplexed for efficient use of the available channels, either in the ground or space segments of the CPS system.

Classes that can be supported by 56 kbps channels, and voice at 64 kbps, have widespread application also. These classes, in some cases combined in an alternate voice-data service, satisfy a large part of the smaller users requirements.

There are several classes, including video teleconferencing which is projected to be widely used, that require greater than a 1.544 Mpbs data rate. Channels supporting services requiring data rates of 56 kbps or greater are currently not widely available but can be provided efficiently by satellite systems, including a CPS system, and are included.

For convenience the many traffic classes have been combined into the following five for most further discussions:

Data-Computer	9.6 kbps or less

Data-Messages	56 kbps
Voice	64 kbps
Video Conferencing	3 Mbps (2T1)
Video Information	6 Mbps (4T1)

Potential user classes encompass most all communications users. An analysis of the traffic classes that users in the various classes would employ, the number of potential users in each class, their geographic distribution and their average annual communications expenditures shows, as mentioned previously, that voice communications is wanted by all users and low data rate services are widely applicable as are 56 kbps services.

These services satisfy much of the needs of smaller users and since some of these, such as municipalities, small institutions and farms, are located outside SMSA's, where ground networking for user communications concentration is not economically attractive, a market for low cost, low aggregate rate, standalone Earth Station's exists. This indicates that the CPS system should be configured to support such services.

An examination of the geographic distribution of user facilities along with communications expenditures shows that the major users, in terms of expenditures per unit and system capacity utilized, are large businesses and large government agencies and these are geographically dispersed. Therefore, they are candidates for subnetwork applications. As a group, this is also true for institutions where subnetworks for educational and medical data exchange are possibilities. These users provide the base for initial system growth which is important in achieving low service costs. If achieved, these low costs make possible offering the services to the other user groups at competitive costs.

Private homes and condominiums provide a significant potential market. However, concentration of communications is necessary to achieve sufficiently low cost service offerings so as to make them attractive to the private user. CATV is a potential transmission medium for this application.

Based on an examination of the CPS traffic classes identification and characterization and the user class characterization, the recommended CPS service offerings include all of the five traffic classes listed previously.

Although Data-Messages and Data-Computer services do not generate a large part of the total traffic, the two classes combined account for about 7% of the traffic. Because all user classes use these services it is recommended that they be provided.

The relative shares of the traffic devoted to the several traffic classes depend on the availabilities provided. For voice services the share of the traffic ranges from 35% to 41%, for video services it ranges from 38% to 44%, for video information services the share is 20%, for Data-Messages it is 3% and Data-Computer it is 4%. The range in the first two classes is due to the effect of availability with the first number being associated with 99.5% and the second with 99.9%. That is, for services requiring high availability, such as voice, increasing the availability from 99.5% to 99.9% results in a greater share of the traffic being devoted to such services.

Although, as indicated, the relative shares of the capacity used by the services is not very sensitive to availability, the total market is.

The Market Postulation Task is summarized in Table 1.1-1. The captured traffic depends upon the conflicting requirements of availability and competitive costs. The large difference in the captured traffic suggests a design for high availability that will reduce costs through economy of scale.

All conventional traffic plus classes requiring higher data rate channels, higher than are generally available currently, are potential classes supportable by a satellite system. Voice and video conferencing are the classes making the greatest demand on the system capacity.

Large business is the most important user class to the system in that this class generates the greatest amount of traffic, has requirements for subnetworks and is a potential source traffic early in the system life, which is important to achieving low service costs. Institutions and Large Government Agencies generate less traffic but are important sources of traffic

Table 1.1-1. Market Postulation Task Summary

YEAR 2000 TRAFFIC	• 3 to 5 GBPS for 99.5% AVAILABILITY AND COMPETITIVE COSTS • 15 to 33 GBPS FOR 99.9% AVAILABILITY AND COMPETITIVE COSTS
TRAFFIC CLASSES	• ALL CONVENTIONAL TRAFFIC - VOICE, LOW SPEED DATA, 56 KBPS DATA • HIGH RATE TRAFFIC - VIDEO CONFERENCING, VIDEO INFORMATION
USER CLASSES	• ALL COMMUNICATIONS USERS ARE POTENTIAL SUBSCRIBERS - VOICE AND VIDEO CONFERENCING ARE MAJOR TRAFFIC CLASSES USED - PRIVATE CLASS REQUIRES COMMUNICATION CONCENTRATION TO ACHIEVE THE REQUIRED LOW COSTS • LARGE BUSINESS IS MAJOR SOURCE OF TRAFFIC, CAN USE SUB-NETWORKS AND IS GOOD POTENTIAL SOURCE OF EARLY TRAFFIC • INSTITUTIONS ARE SECOND LARGEST SOURCE OF TRAFFIC AND HAVE CHARACTERISTICS OF LARGE BUSINESS • LARGE GOVERNMENT CAN USE SUBNETWORKS AND IS SOURCE OF EARLY TRAFFIC • SMALL/MEDIUM BUSINESS, MUNICIPALITIES AND SMALL INSTITUTIONS HAVE SIMILAR REQUIREMENTS AND PRESENT A NEED FOR LOW-COST SMALL ES.
TRAFFIC DISTRIBUTION	• 67% FROM URBAN AREAS - CONCENTRATION VIA GROUND NETWORKING IS POSSIBLE • 33% FROM RURAL AREAS - STANDALONE STATION REQUIREMENTS

early in the system life. Assuming sufficient capture of traffic from the preceeding classes, Small/Medium Business and Municipalities can be brought into the system.

Most of the traffic is generated in urban areas where ground networking can be used to reduce service costs. However, about one third is generated in rural areas where standalone stations would be required. For small users a need exists for low cost, low rate earth stations.

1.2 DEFINITION OF THE CPS GROUND SEGMENT FOR THE SATELLITE SYSTEM

Wideband digital communications in the United States are technologically feasible and promise to increase productivity and decrease the cost of doing business.

To realize the full potential of wideband digital communications, end-to-end services must be established between the ultimate users of the service. Satellite communications networks are capable of providing such channels directly, but a certain minimum traffic volume is required to economically justify an on-site earth station. Thus, many occasional and low volume users are not able to afford a dedicated earth station on their premises. These smaller users, particularly those on urban areas, can share in the benefits of wideband digital communications. Means exist for establishing wideband links between subscriber sites and the nearby Customer Premise Service (CPS) earth station and new regional data distribution media are also under development. Through the use of these existing and planned systems, 30/20 GHz CPS satellite earth station resources may be shared among a larger number of end users, thus increasing the availability of service and permitting the cost of the earth station itself to be spread over a larger number of subscribers. The advantages of long haul satellite communications can be economically realized through the sharing of an earth station among several users, provided the ground networking costs are sufficiently low.

Operation in the 30/20 GHz range provides additional motivation to investigate ground networking options. Link outages due to the relatively severe rain fades experienced at these frequencies can be reduced significantly through the use of space diversity. Rain squalls that cause deep fades are fairly local in extent and additional earth stations within low-cost ground networking range most likely will not experience simultaneous fades. The same

networking media and configurations that provide local loops are capable of providing the inter-station link required to effect space diversity as a means for achieving enhanced service availability.

Regional communications alternatives for wideband communication between Customer Premise Service earth stations and subscribers located off the earth station premises in typical metropolitan areas have been examined.

Both technical performance requirements and operation requirements influenced the system architecture. The technical performance requirements include:

1. Traffic and service models
   a. User configurations
   b. Site locations
   c. Data rates
   d. Blockage

2. Link parameters
   a. Availability
   b. Bit error rate
   c. Delay

The operational requirements fall into three categories:

1. Regulatory and logistics requirements

2. Reliability, availability, and serviceability

3. Expansion/reconfiguration capability

Various wideband digital link candidates examined include:

1. Telco wire pairs

2. AT&T's Dataphone Digital Service (DDS)

3. Point-to-point coaxial cable

4. Point-to-point digital microwave radio

5. Atmospheric optical systems

6. Point-to-multipoint coaxial cable

7. Optical cable

8. Hybrid combinations of the above.

Link type selection is based upon the following characteristics:

1. Capacity
2. Achievable path length
3. Licensing requirements
4. Special installation requirements (if any)
5. Maintenance requirements
6. Costs (recurring and nonrecurring).

In practice, a high degree of commonality among the links selected for the various paths is desirable to promote system serviceability.

Also discussed is the potential application of point-to-point technologies to space diversity links. Finally, cost comparisons for a given scenario of each alternative architecture is presented.

To support the integrated services costing for the CPS network, the earth stations required by each satellite concept are defined and described in sufficient detail to permit all equipment costs to be derived. These costs, generated in a format compatible with the ground network costing methodology, were used to identify the most economically viable combinations of CPS earth stations and ground networking.

The cost of providing end-to-end Customer Premise Service is the major factor affecting the viability of providing such service, in the face of competing technological approaches. Use of existing technology typically leads to earth station unit procurement costs ranging from $100,000 to $800,000. Clearly, the requirement exists for development of new technology and networking concepts that can lead to substantial reductions in ground terminal cost components. Additionally, the costs associated with operation and maintenance of the network and its component earth stations are significant and should be minimized within bounds of providing adequate levels of service. Methods of achieving highly reliable operation with unmanned CPS stations are defined that require achievable Mean Time Before Failure (MTBF) and Mean Time to Repair (MTTR) for CPS ground equipments.

The Earth Station Configurations task effort identified the major subsystem elements needed to construct CPS earth stations for each of the multiple access concepts viable for the 30/20 GHz CPS system. Additionally, methods for cost effective installation, operation, and maintenance of a multiple earth station CPS network are identified and evaluated. From these analyses, a recommendation as to the most pertinent strategies in each of these areas is made.

Three techniques to enhance the path fade margins in the link budgets are examined:

1. Adaptive power control
2. Adaptive forward error correction, and
3. Space diversity

are identified and expressed in terms of:

1. Hardware costs
2. Effects on network operation, and
3. Impacts on network control.

The discussion and evaluation of the fade adaption strategies begin with the definition of link budgets. These link budgets define the required rain fade margins based on the Crane rain model. A discussion of the relative merits of each strategy as applied to each spacecraft concept is followed by a quantitative evaluation for several appropriate applications.

CPS earth station hardware costs are compiled in a format by which both service costing and CPS network optimization can be performed in a consistent and effective manner. This work is based upon the results of CPS earth station configuration analysis.

Two factors that have a large impact upon the CPS configuration costing are the total number of units purchased and the average aggregate station throughput. Quantity discounts can be realized. This is important when determining the optimum combination of earth stations and ground networking.

Quantity discounts are based on learning curves established for the various earth station components and the effects are included in the CPS configuration costing.

With respect to the average aggregate throughput of an earth station in the network, its effect on cost depends upon the configuration. In the TDMA configuration, as the average traffic carried by an earth station increases, the burst rate must increase in order to keep the TDMA induced delays low. In an FDMA configuration, as the aggregate traffic through an earth station increases, so does the number of channels. This, in turn, increases the filtering requirements and the rated power requirements of the local HPA.

The equipment lists for the individual CPS configurations form a unified basis for all costing. Note that the configurations costed include the degree of redundancy required by the desired availability. All elements necessary for a completely installed earth station have thus been included in the costing. The categories from which these costs arise consist of:

1. Electronic hardware
2. Software modules
3. Racks, patches, and cables
4. Shelter
5. Environmental control
6. Site preparation
7. Integration, installation, and test labor
8. Frequency clearance.

Costs for network and DAMA management are assumed to be effectively the same for all of the potential network architectures and hence will not affect the outcome of the service costing comparison. As the cost of such procedures will be shared by all stations in the CPS network, they are best described as a part of network operation and maintenance (O&M). The costs associated with O&M are considered as a fixed percentage of the installed hardware costs for the purposes of the service costing comparison. This percentage is based upon industry experience.

Technology levels that can be expected to exist in the CPS implementation time frame are described. The hardware technology required, particularly in the RF area, are also described.

Costs are presented in T1 increments wherever possible so as to make them compatible with the ground networking costing format. For the FDMA systems, cost sensitivity to earth station aggregate throughput is demonstrated. The cost sensitivities of all station configurations to both throughput and manufacturing production volume are presented in tabular form.

Finally the total installed costs for the various types of CPS earth station configurations are presented. Annual operations and maintenance costs are estimated in terms of a percentage of the installed hardware cost for each configuration.

1.3 DEFINITION OF THE SPACE SEGMENT FOR THE SATELLITE SYSTEM

Four payloads were examined in detail. These are the SS-FDMA, SS-TDMA/Fixed Beam, SS-TDMA/Scanning Beam and a HYBRID FDMA up/TDMA down payload.

SS-FDMA

Satellite Switched-Frequency Division Multiple Access (SS-FDMA) is an adaptation of conventional FDMA to a satellite having a multiple beam antenna and multiple transponders. SS-FDMA makes use of fixed multiple antenna beams, extensive channelization, on-board switching for the purpose of bandwidth reallocation, power diversity for fade compensation and conventional SCPC/DAMA signalling and switching through a Common Signalling Channel to a centralized network control facility. Simple, small, low-cost earth stations result for the small traffic user. Important optimization concepts involve beam combining, to minimize the channelization and switching requirements, and linearized amplifiers to reduce intermodulation distortion. To conserve satellite power multi-mode amplifier operation is important to optimize the power in each beam. Routing through the payload (uplink beam to downlink beam) is determined by a signal's position in frequency; changing the frequency changes the downlink beam. The multiple beam antennas provide multiple contiguous beams covering the entire service area. Frequency reuse is employed to provide higher satellite capacity while the associated higher antenna gain also reduces Earth Station EIRP and G/T requirements.

Signalling and frequency assignment (e.g., switching in the communication sense) is accomplished via a Common Signalling channel (CSC) to a Network Control Center (NCC).

SS-TDMA/Fixed Beam

The and SS-TDMA/Fixed Beam payload concept is based on fixed beam antennas and on-board IF switching for rapid beam interconnect reconfiguration. Rain fade compensation is by means of uplink power control, coding and rate diversity. Signalling and switching use a Common Signalling Channel (CSC) which is part of the burst architecture. The TDMA burst rates are selected to accommodate ES's with capacities equivalent to 1, 4 and 13 T_1 channels.

Routing through the SS-TDMA/Fixed Beam Transponder is dependent upon the time at which the data burst reaches the satellite. The IF switch interconnects the receive and transmit beams in the appropriate sequence, so as to route the data from each uplink beam to the desired downlink beams. The interconnect time between beams is variable, depending upon the amount of information to be transmitted during the time of the interconnect.

As with SS-FDMA, multiple contiguous beams are employed requiring the division of the available bandwidth among the beams to achieve spatial isolation for reducing cochannel interference. Since three TDMA burst rates are employed, the channels in each beam are frequency division multiplexed. The system is basically comprised of several parallel bent-pipe transponders interconnected by the IF switch and does not employ demodulation on the spacecraft. Because a multiplicity of carriers is available, changing earth station aggregate data rate requirements can be accommodated by shifting operation to an appropriate rate carrier as directed by the NCC. As a result, the earth station can be tailored to the current requirements of the individual user.

SS-TDMA/Scanning Beams

SS-TDMA/Scanning Beams utilizes time division multiple access and is an adaptation of TDMA in which scanning spot beams are employed to provide communication between individual earth stations. This approach provides high antenna gain and full coverage, thus making space communication potentially attractive for small users.

The basic approach requires the use of an onboard processor to store and forward the data, after demodulation and reformatting, when the scanning beam is in the correct position.

Scanning may be achieved by a conventional phase array, or by beam hopping with either a reconfigurable MBA or with an N-beam MBA connected to an IF switch. For a given aperture size, the phased array and the MBA will each have a slightly lower G/T than an IF switched MBA because of internal losses. Since the IF switched MBA contains downconverters and IF preamplifiers for each beam as well as a local oscillator distribution network, it will be heavier than the phase array and possibly heavier than the reconfigurable MBA.

In the simplest form only one transponder is required with this concept to connect one uplink to one downlink at a time. However, reduced data rates are obtained through the use of multiple uplinks and downlinks. These are formed by breaking the antenna feed network into subsets of feeds each of which forms a scanning beam.

Ordinarily, the CPS network will contain earth stations of varying size. Therefore, it is appropriate that each scanning beam support several carriers of different burst rates. Banks of demodulators are required to accommodate this variation as well as a bank of downlink modulators. Although the use of multiple carriers in the downlinks requires consideration of intermodulation products, efficiency can be made high by driving the power amplifier into saturation and choosing downlink frequency plans that cause the resulting intermodulation products to fall out of band.

Since only users in one beam position operate at a time, the burst data rate must be at least N times faster than for an FDMA system (N is the number beam positions in the scanned sector). Therefore, the Earth Stations require a proportionately larger antenna and HPA. Also, multiple users in a beam position will further increase in the burst rate.

In the concept analyzed, multiple carriers per beam are utilized and these carry burst rates from 27.5 Mbps to 440 Mbps depending on the traffic requirements in the scanned sector. Also, fixed beams are used to carry traffic from areas of high traffic density.

HYBRID

In the HYBRID, FDMA uplink/TDMA downlink, system concept there are multiple uplink channels for each cell as in the SS-FDMA system. Multiple carriers are used to tailor the data rate to the user requirements and avoid unnecessary burdens of high-speed burst operation, which requires high-speed modems and a large HPA. Access through the satellite beams is determined by the carrier frequency, similar to SS-FDMA. However, since the data is reformatted into a TDM downlink stream, onboard demodulation, processing and remodulation is required. In addition, the earth station G/T and the satellite EIRP must support the high burst rate on the downlink.

The HYBRID system concept uses a fixed beam receive and transmit antennas. Each beam has a low noise preamplifier, receiver and frequency division demultiplexing equipment (channelizing units), followed by on-board demodulation. The baseband processor has convolutional decoding capability for rain fade compensation and in it the downlink data is reformatted into a TDM'd bit stream.

Minimizing the burden on the earth station requires maximizing the spacecraft EIRP and making the downlink efficient by reducing overhead and constraining the transmission rate. Rate constraints can be developed through the use of frequency division multiplex (FDM) to support multiple TDM groups within each beam coverage area. Only one frequency is assigned to a TDM carrier and, hence, to an earth station demodulator thereby enabling the use of a continuous coherent demodulator at the earth station and eliminating the need for burst-to-burst acquisition as required in the TDMA/Fixed Beam system.

An examination of the weight and power of the four payloads shows that for the SS-FDMA and the SS-TDMA/Fixed Beam cases the TWTA weight and power dominate these payload parameters. In the SS-TDMA/Scanning Beam and the HYBRID payloads the TWTA and Processor are roughly equivalent in weight but with the processors in these payloads dominating the power requirements. The SS-TDMA systems were found to use the least power and to weight the least.

1.4 DEFINITION OF THE INTEGRATED SATELLITE SYSTEM

Based on the previous tasks and an analysis of system costs it was found that the integrated system should feature high capacity and high availability. Large capacity, if utilized early in the space segment life, minimizes the

service costs. To capture the large market, availabilities of 99.9% or greater are required.

The ground segment features predominately large earth stations with concentration tails in urban areas. The same transmission media used for networking also interconnects the Earth Stations for space diversity operation and to provide backup for equipment failures.

The sensitivity analysis indicate that the SS-TDMA access techniques lead to minimum service costs and these are the candidates for servicing the principal markets.

A secondary technique to minimize earth station costs for smaller users and that interfaces with the primary access techniques is the HYBRID.

The large spacecraft required would be launched via STS/IUS that is expected to be available when required.

1.5 SERVICE COSTS FOR THE INTEGRATE SATELLITE SYSTEMS

Computation of the space segment user annual charges takes into account aggregate capacity, availability, number of beams, earth station antenna diameter and the system. The procedure is to determine spacecraft weight from EIRP and payload power and weight and the investment cost from spacecraft weight.

Satellite EIRP is based on average link budgets over different CONUS rain zones and varies as system, aggregate capacity, earth station antenna diameter, availability, rain zone and whether earth station space diversity is used.

Spacecraft weight determination assumes the power system + payload weight is 45% of spacecraft B.O.L. weight. The use of advanced lightweight solar cells and nickel-hydrogen battery technology with a specific weight 50 lbs/kw is assumed and a 10% weight and power contingency is included.

The space segment lump sum investment is a function of spacecraft weight. Each system includes two orbiting satellites, one is a standby, one ground

spare satellite, and two launch vehicles plus launch insurance for additional launch upon failure.

Lump sum investment is determined from:

1. Three times satellite cost plus two times launch cost plus 1/2 times non-recurring cost

2. Cost versus weight is based on the Unmanned Spacecraft Cost Model - 1981 SAMSO

3. Lump sum investment is expressed as:

   $\ln R = .7625 \ln W + 4.936$ where
   where: R= lump sum investment ($M)
   W= spacecraft B.O.L. weight (k lbs).

Annual space segment charges are computed from lump sum investment assuming a growth rate of 24.75% per year (from market postulation) which results in a space segment whose average "fill" or useage is about 50% of peak capacity. When compared to ground segment, the annual charge factors are about twice as large because of the lower space segment utilization during the initial period of operation.

Sets of equations were developed and used to compute equipment and installed costs for each system as function of capacity per earth station, availability, station diversity, CONUS rain zone, antenna diameter and number satellite beams. For the networked case, the capacity per earth station vs number of facilities per earth station are from ground networking cost model.

Redundant configurations are required for all earth stations to achieve overall availabilities $\geq$ 99.5%. For a given E.S. capacity, rain zone, and availability, greater EIRP's and HPA powers are required for standalone ES's and hence, greater earth station costs are incurred when compared to a shared earth station with diversity back-up.

For a return on investment of 20%, a yearly tax rate of 46%, a yearly expense equal to 15% of initial investment, and a lifetime of 10 years, the annual charge factor for an earth station is about 0.5. That is, the charges are about 50% of the initial investment.

Annual charges to user groups and facility/traffic service charges are based on market postulation data of the number facilities vs capacity and user group/traffic service distribution of peak traffic vs availability

Computation of annual ground network charges to a user takes into account the aggregate capacity, urban region characteristics, transmission media, concentration factors and the use of station diversity. A uniform spacing of facilities in region and equal shareability of all facilities by regional earth stations is assumed. Coverage areas of each earth station are equal.

Other significant parameters used in the procedure are the facility density which depends on urban region and aggregate capacity, number facilities per earth station, capacity per earth station, and line capacity to earth station.

Network costs per earth station are based on the sum of the costs of the ground network from the earth station to facilities and the diversity network.

Transmission media evaluated are microwave radio, fiber optic cable (above ground) and coaxial cable (above ground). Cost data include cable costs versus length and master concentrator charges.

User group/traffic service ground network capacity data are based on peak capacity distribution vs user/traffic service and user facility data from market postulation. Private homes and condominiums are assumed to use existing cable TV tails and these costs are not included.

For a return on investment of 20%, a yearly tax rate of 46%, a yearly expense equal to 15% of initial investment, and a lifetime of 15 years, the annual charge factor for a ground network is less than 0.5.

1.6 SENSITIVITY ANALYSES

Analyses were carried out for the four types of satellite payloads for various system aggregate capacities, availabilities of 99.5% and 99.9%, various capacity earth stations and a range of user facility densities. Also the earth station antenna size, number of satellite beams diversity were varied. Microwave transmission media were assumed for ground networking. The results of these analyses can be summarized as follows:

The space segment costs are the major factor in determination of system service costs. The space segment costs are minimized primarily by reduction in satellite payload weight and power which can be attained by:

1. Employing earth station space diversity and/or reducing availability in the zones with high degree of rain fading (zone E)
2. Use of large earth station antennas
3. Use of the optimum number of satellite beams

Other significant results are:

1. The use of high capacity systems (15 Gbps) results in considerable reduction in service costs
2. The space segment "fill" factor results in annual service costs for the space segment which are about twice as large as those for the case of 100% fill during the initial year of operation
3. The networked systems show significant advantage over standalone stations because the decreased earth station costs more than offset the networking costs
4. The use of a 20 Mbps (13 T_1) earth station in a network configuration exhibits noticeable cost reductions when compared to smaller capacity configurations. Increasing the capacity above 20 Mbps per earth station results in only small savings
5. The fixed beam SS-TDMA system exhibits minimum costs for all availabilities and capacities in the range from 3 Gbps to 15 Gbps (except for 3 Gbps where the scanning beam SS-TDMA system offers a slight advantage)
6. The variation in urban facility density from light urban to heavy urban has less effect on system cost than variations in earth station capacities from large to small values

1.7 IDENTIFICATION OF CRITICAL TECHNOLOGY

The only technology innovation in the spacecraft which will require a technology development in the ground station baseband equipment is the on-board processor. Most existing TDMA control schemes and synchronization algorithms depend upon unimpeded RF loopback through the satellite. The baseband processor on the 30/20 GHz spacecraft breaks this loop and adds a variable and unpredictable time delay to the signal transit time. This precludes either open or closed loop synchronization and acquisition involving one or more ground stations. In fact the synchronization and acquisition

functions need to be transferred to the baseband processor. This type of network control is an immature technology and as such will require a development effort.

In the spacecraft the critical technology not currently under development by NASA concerns the spacecraft attitude control and the antenna pointing. Large solar arrays are anticipated and these are not rigid structures which is of concern in attitude control. Large antennas, with the associated narrow beams, require precise point. Sun loading may be a significant problem in that case and means for minimizing the reflector distortion or compensating for it require investigation.

SECTION 2

TASK 1 - CPS MARKET POSTULATION

SECTION 2

TASK 1 CPS MARKET POSTULATION

At present the primary transmission mode of the long haul communication traffic is by terrestrial links. This traffic is being supplemented by C-Band satellite links. Because of the limited expansion capabilities of these media, the Ku-Band and Ka-Band satellite systems will be called upon to satisfy the demand for additional channels and service. It is visualized that Ka-Band (30/20 GHz) CPS satellite systems will be implemented in the 1990 to 2000 time frame on a significant scale.

In the CPS market postulation, the traffic classes, traffic distribution both geographically and by traffic service, and user class statistical data are analyzed. From these data, CPS service offerings are classified. In addition, an estimate of the 30/20 GHz CPS satellite system traffic characteristics (capacity, density) is made for the 1990-2000 decade versus traffic class, geographically (satellite beam and regional area), user class and per user. These data are utilized in the evaluation of the ground and space segments and in the sensitivity analysis.

2.1 IDENTIFICATION AND DESCRIPTION OF CPS TRAFFIC CLASSES

CPS satellite systems can support a broad variety of traffic classes. A description of these classes are given in References 1, 2 and 3. However, some potentialities of the CPS satellite system are obtainable from application oriented system designs such as that by General Electric Telecommunications and Information Processing Operations (TIPO) (Reference 7). Potential primary traffic classes for a 30/20 GHz CPS satellite system include:

1. Telephony - The CPS system can include point-to-point telephone, private or leased line networks, and will be primarily used by business, Government, and institutions. These can be exemplified by future "DIAL COMM" type subnetworks (Reference 7).

2. Electronic Mail - This class includes mail box services between local post offices but can also include point-to-point transmission of documentation such as by word processors and TWX/TELEX and administrative messages.

3. Document Communications (Facsimile) - This class is considered separate rather than a subclass of electronic mail and can include operational facsimile (between mailrooms of various businesses), convenience facsimile for time priority service, and special purpose facsimile for transmission of graphics, newspapers, and hard documents which can support video conferences. The facsimile traffic class differs from electronic mail primarily because the former may require transmission of large data rates during peak hours.

4. Video Teleconferencing - This traffic class will allow business meetings among participants in geographically separate locations. Attendees will not only be able to hear and see each other, but will be able to conveniently transmit hard copy, visuals and data they may need to work together in a conference. Through integration of this traffic class with the document communications traffic class, video conferencing can replace much of costly travel and improve the timeliness of meetings.

5. Financial and Electronic Fund Transfer (EFT) - This traffic class can provide actual transfer of funds from bank account to account or can be used for credit checks. This traffic class is characterized by inquiry/response type data traffic from terminal to computer with time priority low data rate transmission plus data entry and transfer computer to computer traffic for transmission of bulk account data for economy.

6. Point of Sale (POS) - This traffic class parallels the usage exhibited by EFT and involves recording of retail transactions and inventory flow for retail markets.

7. Computer-to-Computer Communications "A" - This traffic class is defined as requiring relatively large amounts of communications throughput for data base exchange, memory transfer, etc. Much traffic which is direct from computer to computer includes transfer of data from one storage bank to another usually during off-peak hours and scheduled batch processing.

8. Computer-to-Computer Communications "B" - This is second of two generic computer data exchange services. In this case the average throughput per user is low and because of the nature of the shared service (timesharing and packet switching) the exchange is at a high transmission rate.

9. Library Search, Query and Response - In this traffic class or the more generic Archiving (File, Search, Retrieval), a user files data in a central facility for later retrieval, or is searching the files for retrieval. Much of the time is consumed by interactive queries relating to file locations and addresses although there can be requirements for large amounts of bulk data transfer in the actual filing or retrieval of data.

10. Reservation Data (Airlines, Hotels) - This class is characterized by its urgency and the data is usually transmitted in a real-time manner by the use of operator - entered inquiries to an existing database which can be manipulated and corrected.

11. General Data Collection and Transfer Services - This class involves applications which result in collection of data from transducers for transfer to a central computer. Examples are meter readings from utilities or environmental status (water level, temperature, seismic data). The throughput per transducer is low. These transducers are widely dispersed (long haul cases predominate for CPS service) and the time factor is only critical in applications which require Communications for alarm purposes.

12. Information Services (Broadcast or Interactive Call Up) - In this class network video or Cable TV (CATV) functions are extended to CPS for miscellaneous information services such as educational video, health, and public affairs. These services can have provision for interactive call-up.

There exists the possibility for secondary CPS traffic, i.e., traffic which would not, on its own, warrant the establishment of a CPS link, but given an existing link, becomes a possible service. Such secondary traffic classes can include:

1. Secure Voice Communications - This class utilizes digital transmission which is encrypted. Transmission can use dedicated telephony links.

2.. Narrowband Teleconferencing - This class depends on the primary telephony (high quality audio) and document communications (facsimile or freeze frame TV) for graphics.

3. Command and Control - This class depends on the primary data collection and transfer class and can utilize this data for command and control capability.

4. Automatic Billing Services - This secondary CPS service depends on the data collection and transfer class.

A summary of the characteristics of the above primary and secondary traffic classes are presented in Table 2.1-1. These classes are described according to the various requirements given in the table. Most classes utilize one primary traffic type (voice, video or data). However some use two types such as video/data, video/voice, and voice/data in an integrated fashion.

The transmission rates vary from the relatively high rates for video or high data rate document communications to the very low data rates of several classes (although bulk transfer of data may be utilized for data updates). These low data rate classes would result in very inefficient transmission by telephone DIAL networks (.5%) or dedicated lines (.1%). Packet switching for

Table 2.1-1. Characteristics of CPS Traffic Classes

TRAFFIC CLASS	TRAFFIC TYPE	TRANSMISSION RATES	NUMBER OF TRUNKS PER CPS USER	MULTIPLEXING REQUIREMENTS (CONCENTRATION DISTRIBUTION)	CONTROL OPTIONS (SIGNAL SWITCH ADDRESS)	INTERFACE REQUIREMENTS (WITH EXISTING SYSTEMS)	TERMINAL EQUIPMENT	SERVICE REQUIREMENTS: BUSY HOUR TO AVERAGE HOUR TRAFFIC	SERVICE REQUIREMENTS: WAITING TIME	SERVICE REQUIREMENTS: AVAILABILITY REQUIREMENTS	PERFORMANCE REQUIREMENTS	NOTES:
A. PRIMARY												
1. TELEPHONY	VOICE	64 KBPS	MULTIPLE	WIDESCALE DISTRIBUTION AND CONCENTRATION	FULL SIGNALING SWITCHING ADDRESSING	TELEPHONE SWITCHING CENTERS (DIGITAL), ECHO CANCELLATION	USER TELEPHONES AND SWITCHBOARDS	3:1	SECONDS	HIGH	MINIMAL NOISE AND CROSSTALK	BIT - ERROR RATES LOW $\ll 10^{-8}$
2. ELECTRONIC MAIL	DATA	2.4 KBPS TO 1.5 MBPS	ONE TO MULTIPLE	(DEDICATED LINES) SMALL TO MODERATE MULTIPLEXING	ADDRESS AND SWITCHING	WIDE VARIETY OF TERMINALS FOR WPS AND LACK OF COMPATIBILITY BETWEEN WORD PROCESSORS OF DIFFERENT COMPANIES	WORD PROCESS EQUIPMENT WORD PROCESSORS	2 TO 2.5 WPS 4 OTHERS	HOURS TO MINUTES	LOW TO MEDIUM	MODERATE BIT ERROR RATES	MODERATE 10^{-4} TO 10^{-8}
3. DOCUMENT COMMUNICATIONS	DATA	56 KBPS TO 6.3 MBPS	ONE TO MULTIPLE	(DEDICATED LINES) SMALL TO MODERATE MULTIPLEXING	ADDRESS AND SWITCHING	MINIMAL WITH HIGH RATE HARD COPY DOCUMENT EQUIPMENT. DIVERSE TERMINAL TYPES - FACSIMILES	HIGH SPEED HARD COPY EQUIPMENT FACSIMILES	2 TO 4	SECONDS TO HOURS	HIGH TO MEDIUM	MODERATE BIT ERROR RATES	AVAILABILITY HIGH 0.999
4. VIDEO TELECONFERENCING	VIDEO DATA	3 TO 6 MBPS	ONE	MINIMAL (DEDICATED LINES)	ADDRESS	MINIMAL (USE OF SATELLITE COMMUNICATION EARTH STATION CONTROLLER - ADAPTER)	VIDEO DISPLAYS DOCUMENT DISTRIBUTION EQUIP.	2.50	SCHEDULED	HIGH DURING TIME SCHEDULED	GOOD PICTURE QUALITY. MODERATE BIT ERROR RATES	MEDIUM 0.995 TO 0.999 LOW 0.99 TO 0.995
5. FINANCIAL AND ELECTRONIC FUND TRANSFER (EFT)	DATA	$<$2.4 KBPS WITH BULK TRANSFER OF CLASS #7	ONE	(DEDICATED LINES) SMALL TO MODERATE COMPLEXING	ADDRESS AND SWITCHING	WITH BANK COMPUTER FACILITIES - MINIMAL (WITH PACKET SWITCH)	VIDEO DISPLAYS COMPUTER TERMINALS	4	SECONDS (EXCEPT DURING BULK TRANSFER)	HIGH	LOW BIT ERROR RATES	
6. POINT OF SALE (POS)	DATA	$<$2.4 KBPS	SHARED	MINIMAL (SHARED USERS)	ADDRESS AND SWITCH (PACKET)	MINIMAL (PACKET SWITCH DISTRIBUTION) OR TELEPHONE SWITCHBOARDS	VIDEO DISPLAYS COMPUTER TERMINALS TELEPHONE CALL-UPS	4	SECONDS	HIGH	LOW BIT ERROR RATES	
7. COMPUTER-TO-COMPUTER "A"	DATA	2.4 KBPS TO 56 KBPS	ONE	MINIMAL	MINIMAL	COMPUTER INPUT PORTS	COMPUTER	3	MINUTES TO HOURS	MEDIUM	LOW TO MODERATE BIT ERROR RATES	
8. COMPUTER-TO-COMPUTER COMMUNICATIONS "B"	DATA	$<$2.4 KBPS	SHARED	MINIMAL (SHARED USERS)	ADDRESS AND SWITCH (PACKET)	MINIMAL (PACKET SWITCH DISTRIBUTION) OR TELEPHONE SWITCHBOARDS	COMPUTER TERMINALS	4	SECONDS	HIGH	LOW TO MODERATE BIT ERROR RATES	
9. LIBRARY SEARCH, QUERY, AND RESPONSE	DATA	$<$2.4 KBPS WITH BULK TRANSFER OF CLASS #7	SHARED	MINIMAL (SHARED USERS)	ADDRESS AND SWITCH (PACKET)	COMPUTER STORAGE (ARCHIVES); MINIMAL (WITH PACKET SWITCHING)	VIDEO DISPLAYS COMPUTER, TERMINALS	4	SEVERAL SECONDS TO MINUTES	HIGH	LOW TO MODERATE BIT ERROR RATES	
10. RESERVATION DATA (AIRLINES, HOTELS, ETC.)	DATA	$<$2.4 KBPS	SHARED	MINIMAL (SHARED USERS)	ADDRESS AND SWITCH (PACKET)	MINIMAL-(PACKET SWITCH DISTRIBUTION) OR TELEPHONE SWITCH BOARDS	VIDEO DISPLAYS COMPUTER TERMINALS ALARMS	4	SECONDS	HIGH	LOW TO MODERATE BIT ERROR RATES	
11. GENERAL DATA COLLECTION AND TRANSFER SERVICES	DATA	$<$2.4 KBPS	SHARED	MINIMAL (SHARED TRANSFER FROM COLLECTION POINTS	ADDRESS AND SWITCH (PACKET)	MINIMAL (PACKET SWITCH DISTRIBUTION) OR TELEPHONE SWITCHBOARDS	VIDEO DISPLAYS COMPUTER TERMINALS ALARMS	2	MINUTES TO HOURS (EXCEPT FOR ALARM)	MEDIUM TO HIGH	LOW BIT ERROR RATES	
12. INFORMATION SERVICES (BROADCAST OR INTERFACE CALL-UP)	VIDEO & VOICE	7 MBPS TO 21 MBPS	ONE TO MULTIPLE	(DEDICATED LINES) SMALL TO MODERATE MULTIPLEXING	ADDRESS	WITH DIVERSE TYPE OF METER OUTPUTS - ANALOG TO DIGITAL, ETC. - MINIMAL (PACKET SW.TCH)	VIDEO DISPLAYS (HEALTH, EDUCATION, PUBLIC AFFAIRS) TELEPHONE CALL-UPS	2.50	SECONDS TO 1 DAY	LOW TO HIGH	GOOD TO EXCELLENT PICTURE QUALITY	
B. SECONDARY												
1. SECURE VOICE COMMUNICATIONS	DATA	32 KBPS TO 64 KBPS	MULTIPLE	SOME CONCENTRATION AND DISTRIBUTION	SIGNALING, SWITCHING AND ADDRESSING	WITH TELEPHONE SWITCHING CENTERS: ECHO CANCELLATION	DECRYPTER EQUIPMENT & USER TELEPHONES	4	SECONDS	HIGH	MODERATE BIT ERROR RATES	
2. NARROW BAND TELECONFERENCING	VOICE DATA	64 KBPS	MULTIPLE	SOME CONCENTRATION AND DISTRIBUTION	SIGNALING, SWITCHING, AND ADDRESSING	WITH TELEPHONE SWITCHING CENTERS. WITH FREEZE FRAME TV OR FASCIMILE TERMINALS	USER TELEPHONES VIDEO DISPLAYS FASCIMILES	3	SCHEDULED	HIGH DURING TIME SCHEDULED	MODERATE BIT ERROR RATES	
3. COMMAND AND CONTROL	DATA	$<$2.4 KBPS	SHARED	MINIMAL (SHARED DATA COLLECTION)	ADDRESS AND SWITCH (PACKET)	MINIMAL (PACKET WITH SWITCH) DATA COLLECTION TO CONTROL ROOMS OR CENTERS	VIDEO DISPLAYS COMPUTER TERMINALS ALARMS	2	MINUTES TO HRS. (EXCEPT FOR ALARMS)	MEDIUM TO HIGH	LOW BIT ERROR RATES	
4. AUTOMATIC BILLING SERVICES	DATA	$<$2.4 KBPS	SHARED	MINIMAL (SHARED TRANSFER FROM COLLECTION POINTS)	ADDRESS AND SWITCH	MINIMAL (WITH PACKET SWITCH) DIVERSE TYPE OF METER OUTPUTS (ANALOG, DIGITAL) WITH COMPUTER STORAGE EQUIPMENT BILLING	BILL PROCESSING EQUIPMENT	2	HOURS TO DAYS	LOW TO MEDIUM	LOW BIT ERROR RATES	

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the transmission mode would result in efficiencies of about 50%. The CPS transmission can be routed to the user via several trunks as in the case of telephony or have a single trunk which is shared as in the case for the low data rate traffic which is ideally suited for packet switching transmission mode.

The requirements for concentration and distribution from users (multiplexing) can vary from widescale multiplexing as in the case of telephony to minimal distribution where point to point communications occur as in video conferencing. In the latter, direct connections most likely could be implemented from the earth station to the conference room via the satellite communication systems controller and port adapter systems.

The control functions include switching, signaling, and addressing. The non-dedicated switched networks often require signaling tones within the bandwidth of the channel for the control of the network. The use of dedicated networks or packet switching eliminates the need for signaling tones. The requirements of all of the three control functions are needed for the switched telephone network. Most other of the traffic classes need just addressing and switching for control functions except for the case when a direct line is used.

Interfaces with existing traffic class terminals from the CPS earth station is also a design issue. In telephony, echo cancellation for satellite transmission is an interface requirement. In addition, the ability to interface diverse terminal types is important in electronic mail applications where the lack of compatibility between communicating word processors produced by different manufacturers could also exist as it does in the present time (Reference 3).

In USPS electronic mail service, messages may have to be delivered to a wide variety of terminals. For document communications facsimile networks, the incompatibility of end user equipment is also a consideration (Reference 3).

The use of packet network for the case of low data rate traffic classes can simplify the interface with terminals (Reference 3).

The switches can effect code and speed conversions which enable users with otherwise incompatible terminals to communicate with each other through the network. Many different types of computers can be linked and made accessibly to users having many different types of terminals.

In general, the interface is handled by a terminal box (PORT ADAPTER SYSTEM) which connects the terminals to the earth station. The later consists of MODEMS, CODECS, CONTROLLERS, ANTENNA, etc. The interface may also include error correction, error detection decoders for the traffic classes in Table 2.1-1 with low bit error rate requirements and encryption equipment for secure voice links (option).

The terminal types listed are in many instances computer terminals with the design particulars dependent on the traffic class. In addition, dependent on traffic class, the terminals include telephones, high speed document copying equipment, word processors, video displays, etc. The key issues are the interface requirements with these terminals which is discussed above.

The busy hour to average hour traffic is presented for the various classes with the estimates obtained from References 1 and 2. For business day type traffic these peak ratios can be of the order of four to one while for off-peak traffic such as in computer data exchange these peak factors are reduced by a factor or two. The above peak factor estimates can fluctuate because in addition to hours of the day, the peak factors can have substantial day-to-day variation and seasonal variation but the ones selected will serve as a ground rule. These are also influenced by pricing policies for off-peak traffic.

Other time value functions are associated with service requirements of waiting time and availability. Many of the traffic classes require seconds to tens of seconds (telephone, interactive data applications). Some traffic is able to accept short delays of up to several minutes, as is common in many facsimile applications and in applications involving inquiries to remote data bases (Library Search). Delays of up to several hours are applicable to electronic mail systems for which a response faster than that provided by postal mail service is desired. Delays up to one day allow the transfer of traffic to lightly loaded night-time periods and permit optimum flexibility in resource utilization.

The availability requirements are associated with outage tolerance by users of the various traffic classes (References 1 and 2). The measures listed in Table 2.1-1 are qualitative and are linked to values between greater than 99.9% (high), between 99.5% to 99% (medium) and 99% to 99.5% (low). These numbers express the percentage of time for which acceptable performance is achieved. For example, greater than 99.9% corresponds to an aggregate outage of less than nine hours per year.

The performance requirements in Table 2.1-1 are linked to bit error rate. Signal-to-noise requirements will vary for a given bit error rate depending on the modulation type, character and error correcting codes, etc. In general, traffic classes which have a significant outcome due to precision of data transfer (electronic fund transfer, metering and billing) will have requirements for low bit error rates.

Bit error rate performance requirements of a 1200 bps data link utilizing a switched terrestrial telephone network for transmission (Reference 3) for long haul service are:

Bit Error Rate	Percent of Dial-Ups
4×10^{-7}	25%
10^{-6}	40%
10^{-5}	75%
10^{-4}	93%

Other performance parameters are also significant. For data communications, performance quality is also influenced by phase jitter, sudden amplitude and phase jumps, brief dropouts of transmission, crosstalk from other channels, non-linear distortion, and many other effects.

For telephony, important quality performance parameters are noise, crosstalk and amplitude frequency response. At 64 Kbps, performance quality of telephone links should offer no problems.

Video performance quality depends on parameters such as amplitude frequency response, envelope delay distortion, transient response, noise (thermal, intermodulation, crosstalk and impulse) differential gain and differential phase (last two important for color).

Table 2.2-1. Description of CPS User Classes

	USER CLASS	TRAFFIC CLASSES*	QUANTITY** OF EACH CLASS(UNIT)	GEOGRAPHIC LOCATION	PHYSICAL DISTRIBUTION	AVER PLANT SIZE ** NUMBER OF PER USER UNIT	ANNUAL COMMUNICATION EXPENDITURE PER USER UNIT	EXISTING	AVAILABLE	USED (EXAMPLES)	APPLICABLE
BUSINESS	Large Businesses (Fortune 500 companies)	All classes of Table 1.1	1,544	REF 5 -Location corporate headqtrs Ref 6 Distribution of facilities Ref. 4 pages below	Manufacturing-facilities scattered nationwide Wholesalers-concentrated in central trading areas Retailers-storage scattered nationwide Banks-concentrated regionally Insurance & Stock Brokers-geographically dispersed	16,900 employees	$4,850,000	Telephone networks micro-wave radio relay, coaxial cable, fiberoptics cable, data links	non-saturated links or on legal or economic basis	Dialcom Recom	
BUSINESS	Medium and small Businesses	Primary 1,2,3,8,10 11 & 12 Secondary 2	89,296	By state Ref 4 Pgs. 532,533,547, 555,590,615, 749, 752,760,805,834,835, 839,842,843	Single location or region	98 employees	$30,000	above	above	minimal	minimal
GOVERNMENT	Federal Agencies	All classes of Table 1.1	94	Employment by state Pg. 276 Ref 4	Large Number of offices dispersed nationwide	29,400 employees	$19,750,000	above	above	Autodin(DOD) WAMCS Autovin	
GOVERNMENT	Large State & City	All classes of Table 1.1 except 10	65	Expenditures of largest cities; pg 309, ref 4 employment data pg 317 and 320 ref 4	State capitals and major population centers	62,200 employees	$6,350,000	Telephone networks data links, coaxial cable, ratio relay CATV	above	minimal	minimal
GOVERNMENT	Municipalities	Primary 1,2,3,8,9, 11 & 12 Secondary 2	62,281	List of number of local governments by state pg 304 ref 4	Over a single location region	130 employees	$9,600	Telephone coaxial cable CATV	above		
INSTITUTIONS	Large universities & colleges	Primary; all except 5,6,10 & 11 Secondary; 2	199	Enrollment by state Pg 162 ref 4	Campus: several buildings over small area + special centers	20,000 enrollment	$202,000	Telephone networks coaxial cable CATV	above		
INSTITUTIONS	Large hospitals & health care	Primary; all classes except 5,6 & 11 Secondary; 2	797	Hospital facilities by state pg 113 ref 4	One to few buildings over small area	1,500 employees 614 beds	$185,000	Telephone coaxial cable, CATV	above		
INSTITUTIONS	McClum Universities & colleges	Primary; all classes except 5,6, 10 & 11 Secondary; 2	687	enrollment by state pg 162 ref 4	Campus; several buildings over small area	5,800 enrollment	$66,500	above	above		
INSTITUTIONS	Medium Hospitals & Health Care	Primary; all classes except 5, 6 & 11 Secondary; 2	2,040	Hospital facilities by state pg 113 ref 4	One building	590 employees 258 beds	$71,500	above	above		
INSTITUTIONS	Small universities & colleges	Primary; 1,2,3,4,7,8 9, 12 Secondary; 2	2,217	Enrollment by state Pg 162 ref 4	Few buildings close together	900 enrollment	$10,300	above but minimal	above		
INSTITUTIONS	Small Hospitals & Health Care	Primary; 1,2,3,4,7,8 9, 10 & 12 Secondary; 2	4,209	Hospital facilities by state pg 113 ref 4	One small building	150 employees 64 beds	$17,200	above but minimal	above		
PRIVATE	Apartments and Condominium complexes (ref 4)	Primary; 1, 8, 12	14 300 .6a apt. units avg)	Pgs 777, 780 ref 4	Groupings of apartment units in one to several buildings	180	$30,000	CATV telephone links	above		
PRIVATE	Urban and Suburban Homes (ref 2)	Primary; 1, 8, 12	8,200,000 (>$50,000 evaluation)	pgs 777, 780 & 792 Ref 4	Concentration of several homes (~25 to 75)	3	$500	CATV telephone links	above		
PRIVATE	Farms (ref 4)	Primary; 1,8,12	153,00 (sales > $180,000)	pgs 688,689 ref 4	Average acreage 3,304 (ref 4 pg 687)	6	not determined (avg sales $278,000)				

* Traffic class numbers

Primary
1. Telephony
2. Electronic Mail
3. Document Communicat.
4. Video teleconfer.
5. Financial & EFT
6. Point of Sale
7. Computer to computer communications "A"
8. computer to computer communications "B"
9. library search, query & response
10. reservation data
11. General data collection and transfer
12. Information Services

1. Secure voice communications
2. Narrow band teleconferencing
3. Command and Control
4. Automatic billing services

** Quantity of each class and avg plant size based on 1977 data (ref 2) and 1978 data (ref 4)

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In video transmission, the picture quality is linked to bit rates (Reference 3) for example:

Quality	Encoding	Bit Rate Mbps	Comments
Network	PCM (7-8 Bit)	75-86	Excellent Quality Color TV
	Intraframe	32-45	
	Interframe	20-30	
Video Conferencing	Intraframe	6	Quality Good
	Interframe	3	Some Jerking Occasional Picture Freezing
	Interframe with Motion Compensation	1.5	Experimental

It should be noted that the transmission rates listed in Table 2.1-1 are conservative with regard to potential video quality for the year 2000. For example, for video teleconferencing, the video transmission with interframe encoding and motion compensation, the bit rate (2 way) for video teleconferencing may total 3 Mbps for the year 2000 and result in acceptable performance quality.

The above traffic class characteristics are linked to user classes (Section 2.2), CPS service offerings (Section 2.3), and traffic distribution (Section 2.4) in subsequent sections of this report.

2.2 IDENTIFICATION OF CPS USER CLASSES

The user classes identified for CPS service include Business, Government, Institutions, Private, and Farms. These classes are further divided into subclasses according to size or function. A descriptive summary of CPS user classes is given in Table 2.2-1. A further characterization is given below by class type.

2.2.1 BUSINESS

Businesses can be considered to consist of two classes: Large Businesses (including Fortune 500 Companies); and Medium and Small Businesses. The former consists of relatively large employment, large annual communication expenditures and has extensive facilities scattered throughout the United states. These businesses will utilize all of the traffic classes listed in

expenditures and has extensive facilities scattered throughout the United states. These businesses will utilize all of the traffic classes listed in Table 2.1-1. On the other hand, the medium and small businesses are numerous with less than 100 employees each on the average, much smaller communication expenditures, and minimum scatter of facilities. More detail analysis of businesses requires evaluation by business type; Manufacturing, Wholesale and Retail Distribution, Finance/Banking, Insurance, Transportation, Utilities, Professional Business Services and Other.

2.2.1.1 Manufacturing

The largest 1000 manufacturing corporations generate 90% of the total revenues and employ 83% of the total employment from this subclass. The manufacturing industries will utilize all of the CPS traffic classes listed in Table 2.1-1 except for Finance and Electronic Fund Transfer, Point of Sale, Secure Voice Communications, and Automatic Billing Services.

The geographical coverage of a typical large manufacturing industry results in scattering of facilities throughout the United States. Typical examples of geographical and physical distribution characteristic of representative corporations are (Reference 6):

Corporation	Employment	Distribution of Facilities in
General Electric Co.	401,000	228 manufacturing plants located in 34 states 7 Mines
Burroughs Corporation	36,127	28 principal manufacturing and research and engineering facilities in U.S. 80,000 sq. ft. average floor space per facility. 904 sales and service offices in U.S.
TRW	93,353	Approximately 100 facilities in U.S. average floor space 120,000 sq. ft. per facility 8% in Cleveland 20% in Southern California
Xerox	104,736	3 Facilities in Rochester, N.Y. 6 facilities scattered in U.S.

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Corporation	Employment	Distribution of Facilities in
Eastman Kodak Co.	79,600	5 locations in Rochester 4 other facilities scattered in U.S.
United Technology Corporation	152,213	4 facilities near Hartford, Conn. 8 facilities scattered over rest of U.S.

It should be noted that the average number of employees per facility varies from 1000 to 2000 for GE, TRW and Burroughs to the order of 10,000 or more for the remaining three businesses.

Wholesale and Retail Businesses

Large wholesaler types of businesses are primarily concerned with updated merchandise inventory records so the prime traffic classes of interest are telephony, point of sale or computer-to-computer communications, electronic mail and document communications. Large wholesalers are geographically placed at central trading areas with several warehouses strategically located.

Large retailers, on the other hand, even though utilizing the same traffic classes as the wholesalers have facilities scattered nationwide.

Typical characteristics of large retailers are:

Corporation	Sales	Distribution of Facilities
J. C. Penney	$11 billion	Throughout U.S. 2,119 Penney Stores 1,840 Catalog Sales Centers 34 The Treasury Stores 361 Drug Stores
Safeway Stores	$15 billion	1,708 stores in 22 states west of Mississippi 239 stores east of Mississippi 86 Manufacturing and Processing Facilities

Corporation	Sales	Distribution of Facilities
Sears, Roebuck and Co.	$17 billion in merchandising $6.197 billion insurance $419 million real estate and finance	854 retail stores 1,298 sales offices Territorial Merchandising Sears Tower, Chicago, Atlanta, Los Angeles, Phila. 107 warehouses including 56 major distribution warehouses owned 294 warehouses including 31 major distribution warehouses leased Total square footage 116.3 million.

Finance/Banking

The banking industry will require telephony, electronic mail, document communications and electronic fund transfer traffic. Savings and commercial banks are distributed in a limited geographic region because of federal and state laws.

Other finance businesses include stock brokerage firms and exchange houses, and credit agencies which require to a great extent the above traffic classes but with more emphasis on electronic mail and document communications. In addition, library search, query, and response traffic class is significant.

The geographic distribution of the facilities of stock brokerage firms centers about all large metropolitan areas. Of all the stock brokerage firms in the United States, the average number of offices per firm is about 7 (Reference 2).

Insurance/Transportation

The insurance business requires traffic classes (in addition to telephony) which are primarily data communications for the setting up of customer policy records, the processing of premium installments, data base inquiry/response, and the batch processing of regional sales office records. Therefore, electronic mail, document communications, and both types of computer-to-computer communications are required in addition to telephony. The geographical distribution of facilities of large insurance companies is nationwide. The physical distribution of traffic flow is from regional/local offices to headquarters with high volume computer-to-computer traffic to update data bases.

Transportation companies require significant telephony and reservation data traffic services. In addition, electronic mail, document communications, and command and control (secondary) traffic services are required. The major use of the CPS system would be by large airlines, railroads and buses which have facilities scattered nationwide.

Other Businesses

Utility companies have potential use of telephony, electronic mail, document communications, general data collection and transfer services, command and control, and automatic billing service CPS traffic classes. Most utilities operate in a well defined territory rather than being scattered nationwide.

Other businesses include accounting, advertising, management consulting, architectural and computer service firms, construction, mining, fisheries, real estate, and hotel/motels. The above group of miscellaneous businesses will utilize essentially all of the CPS traffic services listed in Table 2.2-1. Some of the above have widespread facilities (hotels/motels, for example).

Business Terrestrial Tails and Subnets

For CPS systems, the terrestrial tails are defined as the links between the earth station interface and the central switching, or other interface at the user facility. Terrestrial tails can be implemented by means of telephone lines, microwave radio, CATV, coaxial cable and fiber optic cable links, the choice depending on existing facilities and traffic.

Currently available and projected technology for implementing terrestrial tails is discussed in Section 3.1.

Subnetworks used by large businesses and government are similar to these installed by the General Electric Company. These include, Dial Comm which provides long-distance voice, dial-up data and facsimile transmission services and RECOMM which provides digital data communications order processing.

These networks are being incorporated into a satellite system. This SBS (Ku-band satellite) system is now in the demonstration development stage using three different test sites. It is planned to expand this to earth stations. This private subnetworks will support the full range of intracompany voice,

data, document and image communications. The teleconferencing, document distribution, data processing, and voice communications facilities are connected to the earth station by a port adapter system.

2.2.2 GOVERNMENT

The Government consists of three separate classes: federal agencies, large state and city agencies, and municipalities.

Federal Agencies

The agencies of the federal government have use for all of the traffic class services of Table 2.2-1 and the offices are widely dispersed throughout the United States (over 11,000 office locations). The six major departments which are Department of Defense, Health Education and Welfare, Treasury, Veterans Administration, Agriculture, and Transportation make up over 60% of user classes communication transmission expenditures. The Department of Defense has 23.5% of the user classes total budget, employs 48.5% of the class's total employment and spends over 23% of the total dollars spent on communication services.

The subnetworks for federal agencies are similar to those for large businesses. Currently subnetworks exist for the USPS electronic mail system and for the Department of Health, Education, and Welfare's large scale computer links.

Other subnets that exist or will be in existence well before the implementation of the 30/20 GHz CPS system include, a large USPS early stage electronic mail subnet, the subnets of the World Wide Military Communication System (WWMCS) which is already in existence and its communications capability is continually being improved and the AUTODIN subnetworks (such as AUTODIN II), which support the data transmission requirements of the Department of Defense and other agencies.

Large State and City Agencies

Large state and city agencies can utilize similar CPS traffic services as the federal government (with the exception of reservation data). The geographic distribution of facilities would be the state capital and large population

centers (which are in most cases separated from capital). In addition, state communication links need be established with various federal departments and agencies.

For the state and city agencies, the terrestrial tails would involve telephone networks, CATV links and some of the local data processing links. No significant subnetworks has been identified.

Municipalities (Medium/Small)

Municipalities will utilize CPS traffic services to a much smaller extent, the potential classes are listed in Table 2.2-1. The administrative facilities of the municipalities are concentrated at one location: The existing terrestrial tails are minimal and consist mainly of telephone and CATV links.

2.2.3 INSTITUTIONS

Institutions considered consist of educational institutions, such as colleges and universities, and health care institutions, including hospitals.

Universities and Colleges

The universities and colleges can make use of most of the traffic classes with diminished use for the smaller size users. With CPS video teleconferencing and high speed document communications attractive possibilities exist for maximum use of nationwide expertise in lecture halls. Extensive use would be made of library search, query, and response, information services, and computer-to-computer communications traffic services.

The distribution of most universities is regional. However, some large state universities may have campuses which are separated. Universities consist of one to several buildings spread over a relatively small area with possibility of some special research centers at nearby locations. The major existing terrestrial tails consist of those associated with telephony or CATV links (cable).

Hospitals and Health Care

Hospitals and health care institutions have functional similarities to universities requiring extensive use of library search, query and response, informational service, and other educational traffic classes for the medical, staff interns and students.

The telephony traffic would be to the medical staff and patients. Hospitals are also restricted to a given region. The terrestrial tails consist primarily of telephone and CATV links.

2.2.4 PRIVATE

Private users consist of those residing in apartments, condominiums, and urban and suburban homes. The major use of CPS traffic services for private users is in the informational services classes. As the annual communication expenditures per private user is relatively low, concentration of many private users is required.

Potential terrestrial tails linking private users to an earth station are telephone and cable TV links. Since all potential users may not have cable TV, some wideband services may not be available to a unit of users.

2.2.5 FARMS

Large farms are potential users of CPS traffic services with communications to market centers, transportation networks and informational services. There are relatively large number of farms with sales over $100,000 and average areas of greater than 3,000 acres. Like private users, some concentration of nearby farms may be required. Similar terrestrial tails exist for farms as for private users.

2.2.6 SUMMARY

The potential applicability of CPS service to various user classes, based on the data given in Table 2.2-1 is:

Large	Medium	Conditional
Large Businesses	Municipalities	Private Homes
Federal Agencies	Medium and Small Businesses	Farms
Large State and City Agencies	Institutions (Small)	
Institutions (Large and Medium)		

The potential applicability of private homes is conditional on the basis of the need for concentration of users. The potential applicability of farms is conditional because of the relative small amount of potential traffic

services. The applicability of CPS services to farms would depend very much on economics and concentration would probably be required except for a few very large farms.

The average number of facilities per user is difficult to determine for businesses because of the wide variation. An estimate of the range of number of facilities per user is:

User Class	Scaling Factor	Average Number of Facilities Per User	Basis
Large Business	Number of Employees	17	1000 is average number of employees
Medium and Small Business	--	1	1 Facility per user
Federal Agencies	Number of Users and States	28	The 4 largest agencies have two facilities in every SMSA; remaining have two facilities per user.
Large State and City Agencies	Number of Agencies and SMSA's	18	Each agency has four facilities in a SMSA
Municipalities	--	1	1 Facility per user
Institutions	--	1	1 Facility per user
Private	Average Communication Expenditures	1	Needs concentration
Farms	Qualitative estimate	1	Needs concentration

The farm user class is not further considered as it represents similar traffic type as private households but for a much smaller quantity of users (less than 10% of the quantity of private homes or condominiums). Furthermore, because of the relatively large spacing between farms (as compared to private homes) the capability to concentrate a large number of users is less because of networking costs.

2.3 CLASSIFICATION OF CPS SERVICE OFFERINGS

Many of the traffic classes listed in Table 2.2-1 have enough characteristics in common to be grouped into fewer classifications. The results of these groupings are shown in Table 2.3-1. These traffic class categories or groupings are:

Voice
Video-Conferencing
Video-Information Services
Data-Messages
Data-Computer

These traffic class groupings constitute the service offerings to the user classes described in Section 2.2, and are analyzed in this section.

2.3.1 CAPACITY CHARACTERISTICS

An analysis of the long haul communication traffic for the years 1990 and 2000 is given in Reference 3 (with additional discussion in Section 2.4, Traffic Distribution). The percentage average throughput traffic for the year 2000 are given in Table 2.3-2. For CPS the relative average long haul communication throughput depends on the service availability. The residential voice service contributes little to the CPS traffic unless widespread concentration is utilized (Reference 3). The video services will contribute a large amount of traffic. For the case of availability of 99.5%, the analysis given in Reference 3, shows reduced traffic for classes which require higher availabilities. Some services are less dependent on the effect of outages (some data message and video services with deferrable waiting times). These are reflected in the relative capacity percentages given in Table 2.3-2.

The other case characterized in Table 2.3-2 is CPS with availabilities of 99.9%. As shown, the relative traffic availability-dependent services is increased. Therefore, a greater proportion of voice services are present.

Table 2.3-1. Traffic Class Groupings

TRAFFIC CLASS	PRIMARY TRAFFIC TYPE	SECONDARY TRAFFIC TYPE	TRAFFIC CLASS CATEGORY
• TELEPHONE	VOICE	-	VOICE
• ELECTRONIC MAIL	DATA	-	DATA - MESSAGES
• DOCUMENT COMMUNICATIONS	DATA	-	DATA - MESSAGES
• VIDEO TELECONFERENCING	VIDEO	DATA	VIDEO CONFERENCING
• FINANCIAL AND ELECTRONIC FUND TRANSFER	DATA	-	DATA - COMPUTER
• POINT OF SALE	DATA	-	DATA - COMPUTER
• COMPUTER-TO-COMPUTER COMMUNICATIONS "A"	DATA	-	DATA - COMPUTER
• COMPUTER-TO-COMPUTER COMMUNICATIONS "B"	DATA	-	DATA - COMPUTER
• LIBRARY SEARCH, QUERY AND RESPONSE	DATA	-	DATA - COMPUTER
• RESERVATION DATA	DATA	-	DATA - COMPUTER
• GENERAL DATA COLLECTION AND TRANSFER SERVICES	DATA	-	DATA - COMPUTER
• INFORMATION SERVICES	VIDEO	VOICE	VIDEO - INFORMATION SERVICES
• SECURE VOICE COMMUNICATIONS	DATA	-	DATA - MESSAGES
• NARROW BAND TELE-CONFERENCING	VOICE	DATA	VOICE
• COMMAND AND CONTROL	DATA	-	DATA - COMPUTER
• AUTOMATIC BILLING SERVICES	DATA	-	DATA - COMPUTER

Table 2.3-2. Service Average Capacity Requirements

Service Category	Percentage Peak Throughput Capacities: Total Long Haul Services	CPS Services Availability 99.5%	CPS Services Availability 99.9%
Voice	75	42.8	49
Video Conferencing	4.7	34.2	29.6
Video-Information Services	2.7	19.3	18.4
Data Messages	0.2	1.6	1.3
Data Computer	7.4	2.1	1.7
Total	100	100	100
Addressable Traffic (Percentage of Total Long Haul Services	100	4.5	15.9

Year 2000 Availability and Cost Assumptions
Availability 99.5%   Relative Cost = 0.7
Availability 99.9%   Relative Cost = 1.0

Table 2.3-3 presents the above cases in terms of peak traffic based on the peak-to-average factors for voice, video and data services listed as a footnote in this table (Reference 3). In terms of peak throughput, the data services have the largest peak factors (busy hour traffic to average hour traffic) and hence contribute to a greater relative peak capacity requirement (Table 2.3-3) than to the average capacity (Table 2.3-2).

The distribution of long haul communications by service versus user class (Reference 1, Page 152) is for year 2000:

	Private	Business	Government	Institution
Voice	13%	58%	17%	12%
Video	1%	64%	3%	32%
Data	1%	67%	19%	13%

Table 2.3-3. Service Peak Capacity Requirements

Service Category	Percentage Peak Throughput Capacities Total Long Haul Services	CPS Services Availability 99.5%	CPS Services Availability 99.9%
Voice	74.4	34.7	40.8
Video-conferencing	5.8	37.8	33.5
Video Information Services	3.3	20	19.4
Data Messages	.4	3.2	2.8
Data Computer	16.1	4.3	3.5
Total	100	100	100

Year 2000 Availability and Cost Assumptions
Availability 99.5%   Relative Cost = 0.7
Availability 99.9%   Relative Cost = 1.0

Busy Hour to Average Hour Traffic: Voice 1.57; Video 2.2; Data 3.9

For CPS applications, these traffic distributions are based on the guidelines given in Reference 3 (Page 55).

In the above references, traffic type/user class data is presented in terms of business, government, institutions and private. The distribution of the traffic between the various user class divisions (such as large business and medium and small business) is assumed to be proportional to the communication expenditures of the user class in question for voice traffic services (see Table 2.2-1). For other traffic (such as video conferencing), the application of such services to a given user group are postulated based on relative size or applicability. The private user is assumed to have widespread concentration (1000:1) and the limitations described in Reference 3 (Page 55) do not exist.

Based on the above data, the relative distribution of average hour CPS traffic for availabilities of 99.5% and 99.9% are given in Tables 2.3-4 and 2.3-5. Similar distributions for busy hour traffic are given in Tables 2.3-6 and 2.3-7.

Table 2.3-4. Year 2000
Relative Average Hour Traffic vs User Class/Traffic Service

99.5% Availability			Service			
User Class	Voice	Video Cont.	Video Info Serv	Data Message	Data Computer	Total User
Large Business	.2702	.2587	0	.00875	.0114	.5481
Small Business	.0690	0	0	.0042	.0043	.0775
Government (Large) Agencies	.0226	.0156	.0312	.00079	.00135	.0715
Municipalities	.0153	0	0	.0009	.00077	.017
Institutions	.0309	.0665	.133	.002	.0029	.2353
Private Homes and Condos (X1000)	.01984	0	.02733	0	.00024	.0474
Total Traffic/Service	.42784	.3408	.1915	.01574	.02096	1
Busy Hour to Average Hour Traffic: Voice 1.57, Video 2.2, Data 3.9						

Table 2.3-5. Year 2000
Relative Average Hour Traffic vs User Class/Service

99.9% Availability			Service			
User Class	Voice	Video Cont.	Video Info Serv	Data Message	Data Computer	Total User
Large Business	.3156	.2173	0	.00667	.00953	.5491
Small Business	.07163	0	0	.00316	.00270	.07749
Government (Large) Agencies	.02951	.01337	.02674	.00068	.00117	.07147
Municipalities	.01572	0	0	.00069	.00059	.01700
Institutions	.03759	.06471	.12943	.00199	.0028373	.23656
Private Homes and Condos (X1000)	.019837	0	.027323	0	.00024	.0474
Total Traffic/Service	.4899	.2954	.1835	.01319	.01707	1
Busy Hour to Average Hour Traffic: Voice 1.57, Video 2.2, Data 3.9						

Table 2.3-6. Year 2000
Relative Peak Traffic vs User Class/Service

99.5% Availability			Service			
User Class	Voice	Video Conf.	Video Info Serv	Data Message	Data Computer	Total User
Large Business	.2176	.292	0	.0157	.0228	.5481
Small Business	.0593	0	0	.0089	.0093	.0775
Government (Large) Agencies	.0173	.0167	.0334	.00151	.00259	.0750
Municipalities	.0134	0	0	.00195	.00167	.01700
Institutions	.0225	.0679	.1359	.0037	.00528	.2353
Private Homes and Condos (X1000)	.016	0	.03088	0	.00048	.0474
Total Traffic/Service	.3461	.3766	.2002	.03176	.04212	1

Table 2.3-7. Year 2000
Relative Peak Traffic vs User Class/Service

99.9% Availability			Service			
User Class	Voice	Video Cont.	Video Info Serv	Data Message	Data Computer	Total User
Large Business	.2624	.2532	0	.01378	.01968	.5491
Small Business	.06441	0	0	.007045	.006038	.07749
Government(Federal & State/City) Agencies	.02335	.01482	.02965	.001344	.002304	.07147
Municipalities	.01413	0	0	.001546	.001325	.01700
Institutions	.02765	.0667	.1334	.00329	.005184	.23656
Private Homes and Condos (X1000)	.016	0	.03088	0	.00048	.0474
Total Traffic/Service	.4070	.3347	.1939	.02734	.03501	1

The data is presented in Tables 2.3-4 through 2.3-7 such that the total traffic of all the user classes is normalized to one. The above format is very useful in determining the total capacity requirement of each user versus service from the matrix type tables for a given peak or average aggregate capacity.

The estimated range of this traffic for the year 2000 is from 3 Gbps to 33 Gbps (see Section 2.4). The year 1990 CPS aggregate peak capacity is about 10% of the year 2000 capacity (Reference 3). For a given case, the total CPS peak traffic of a user class/service category is the peak aggregate traffic for the year in question times the value given in Tables 2.3-4 through 2.3-7 for that user class/service class category matrix element.

The user facility characteristics are estimated from data in Section 2.2 and summarized in Table 2.3-8. The scaling factor is also given in Table 2.3-8. For example, for a large business, the number of facilities is scaled on the basis of 1000 employees per average facility. The CPS services per facility are given in Tables 2.3-9 and 2.3-10 for availabilities of 99.5% and 99.9%. The Federal and Large State/City agencies class and Institutions classes are consolidated to single groupings. The served facilities is based on the captured CPS market scenarios and the applicability of CPS service to a given user class. From the assumption of proportionality of number of served facilities to CPS aggregate traffic, the traffic per facility is independent of the aggregate capacity. For example, for an aggregate traffic of 15 Gbps, the number of facilities served is three times the number of served for an aggregate traffic of 5 Gbps and so the ratio of aggregate traffic to number of facilities is the same for either case.

Data Tables 2.3-9 and 2.3-10 are iteratively estimated from Table 2.3-6 and Table 2.3-7, which give the relative share of traffic vs user group, and Table 2.3-11. For example, in Tables 2.3-9 and 2.3-10, it is assumed that all users of Video Conferencing have a 2T1 channel while all users of video information service have a 4T1 channel. The number of void circuits are assumed to be proportional to average communication expenditure per facility. For 99.9% availability, the relative usage of voice service per facility is assumed to increase based on comparison of Table 2.3-7 with Table 2.3-6 and hence are soaled-up. The data in Table 2.3-11 is computed from Tables 2.3-6, 2.3-7,

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Table 2.3-8. Typical Facility Characteristics

USER CLASS	SIZE FACTOR	NUMBER FOR FACTOR	NUMBER FACILITIES PER USER	COMMUNICATION EXPENDITURES PER FACILITY
LARGE BUSINESS	EMPLOYEES	1,000	17	$300,000
MEDIUM & SMALL BUSINESS	EMPLOYEES	98	1	$30,000
FEDERAL AGENCIES	EMPLOYEES	1,050	28	$337,500
LARGE STATE & CITY AGENCIES	EMPLOYEES	3,660	18	$375,000
MUNICIPALITIES	EMPLOYEES	130	1	$10,000
LARGE INSTITUTIONS	ENROLLMENT NUMBER OF BEDS	20,000 814 BEDS	1	$200,000
MEDIUM INSTITUTIONS	ENROLLMENT NUMBER OF BEDS	5,800 258 BEDS	1	$70,000
SMALL INSTITUTIONS	ENROLLMENT NUMBER OF BEDS	900 64 BEDS	1	$15,000
*PRIVATE HOMES & CONDOMINIUMS		1000	1000	$500,000

*CONCENTRATION IN UNITS OF 1000 ASSUMED

Table 2.3-9. CPS Services Per User Facility

User Class	Voice 64 kbps Circuits	Video Conference 2T1 Channels	Video Info. 4T1 Channels	Computer Message 56 kbps ckts	Computer Data 9600 bps ckts	Peak Cap. Per Facil Mbps
			CPS Service			
Large Business	36	1	0	3	25	5.8
Small/Medium Business	6	0	0	1	5	.49
Large Government Agencies	50	1	1	5	50	13.2
Municipalities	6	0	0	1	5	.49
Institutions (Avg)	16	1	1	3	25	10.7
Private Homes and Condominiums concentrated 1000:1	50	0	1	0	10	9.5

Table 2.3-10. CPS Services Per User Facility

User Class	Voice 64 kbps Circuits	Video Conference 2T1 Channels	Video Info. 4T. Channels	Computer Message 56 kbps ckts	Computer Data 9600 bps ckts	Peak Cap. Per Faci. Mbps
			CPS Service			
Large Business	50	1	0	3	25	6.7
Small/Medium Business	8	0	0	1	5	.62
Large Government Agencies	76	1	1	5	50	14.9
Municipalities	8	0	0	1	5	.62
Institutions (Avg)	20	1	1	3	25	11
Private Homes and Condominiums concentrated 1000:1	50	0	1	0	10	9.5

2.3-9 and 2.3-10. For example, at 99.5% availability, the Large Business user traffic is 54.81% of the total. For 5 Gbps peak, this amounts to 2741 Mbps of traffic.

From Table 2.3-9, a typical Large Business facility has a peak traffic of 5.8 Mbps. Therefore, the number of facilities equals (2741 Mbps) (5.8 Mbps per Facility) or 473 facilities, as given in Table 2.3-11.

The number of user facilities for a peak aggregate traffic of 5 Gbps and availabilities of 99.5% and 99.9% is given in Table 2.3-11. For other capacities the number of facilities is directly scaleable based on aggregate traffic. For the year 1990 both the number of CPS served facilities and CPS aggregate traffic is about 10% of that of the year 2000 (Reference 3). For the year 1990, the CPS system would probably serve the business community Government, and institutions but not the private sector, municipalities or small business.

Table 2.3-11. Number of User Facilities

User	Availability 99.5%	Availability 99.9%
Large Business	473	410
Small Medium Business	794	629
Large Government Agencies	27	24
Municipalities	174	138
Institutions (Avg)	110	108
Private Homes and Condominiums Concentration 1000:1	25	25
TOTAL	1603	1334

- Year 2000
- Peak Aggregate Traffic 5 Gbps
- Scalable to a given system peak traffic, C (Gbps), by multiplying the above number by (C/5)

2.3.2 CPS USER SERVICE REQUIREMENTS

Some CPS user service requirements are summarized in Tables 2.3-12 through 2.3-14. In Table 2.3-12, CPS bit error rate requirements are presented. Typical long haul voice bit error rate requirements range from 10^{-4} to 10^{-6} (Reference 3). The computer data services impose the most stringent bit error rate requirements.

The waiting time requirements are summarized in Table 2.3-13. The waiting time categories in Table 2.3-13 are defined as follows:

- Real Time — Responses times of less than one second to several tens of seconds.
- Short Deferred — Up to several minutes delay.
- Medium Deferred — Up to several hours of delay
- Long Deferred — Up to 24 hours of delay

The available traffic in terms of percentage link availability versus service is summarized in Table 2.3-14. Typical outages for each of the four offerings are:

Offering	Availability (%)	Typical Outages	Relative Cost
1	99.99	5 min. every month	20% Higher
2	99.9	15 min. every 2 to 3 weeks	Reference
3	99.5	25 min. every 3 to 4 days	30% Lower
4	99.0	30 min. every 2 days	35% Lower

For the CPS cases with availabilities 99.5%, the sum of columns (3) and (4) of Table 2.3-14 is an approximate percentage reduction of CPS system traffic due to link availability considerations.

Another CPS service characteristic is the direction of the flow of traffic (into or out from the user CPS facility). For example, voice traffic is approximately equally divided between inflow and outflow. A summary of the

Table 2.3-12. CPS Bit Error Rate Requirements

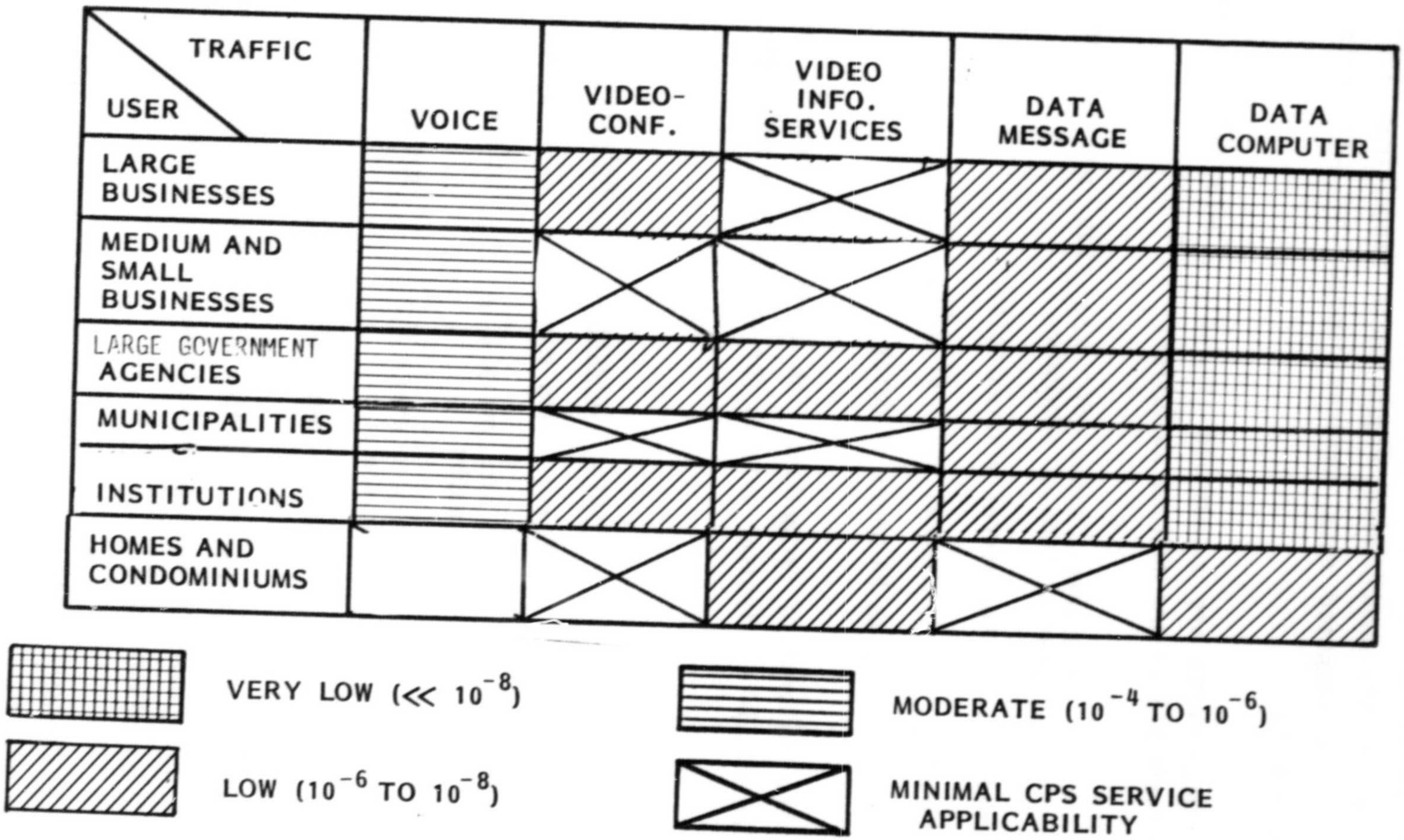

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Table 2.3-13. CPS Waiting Time Requirements

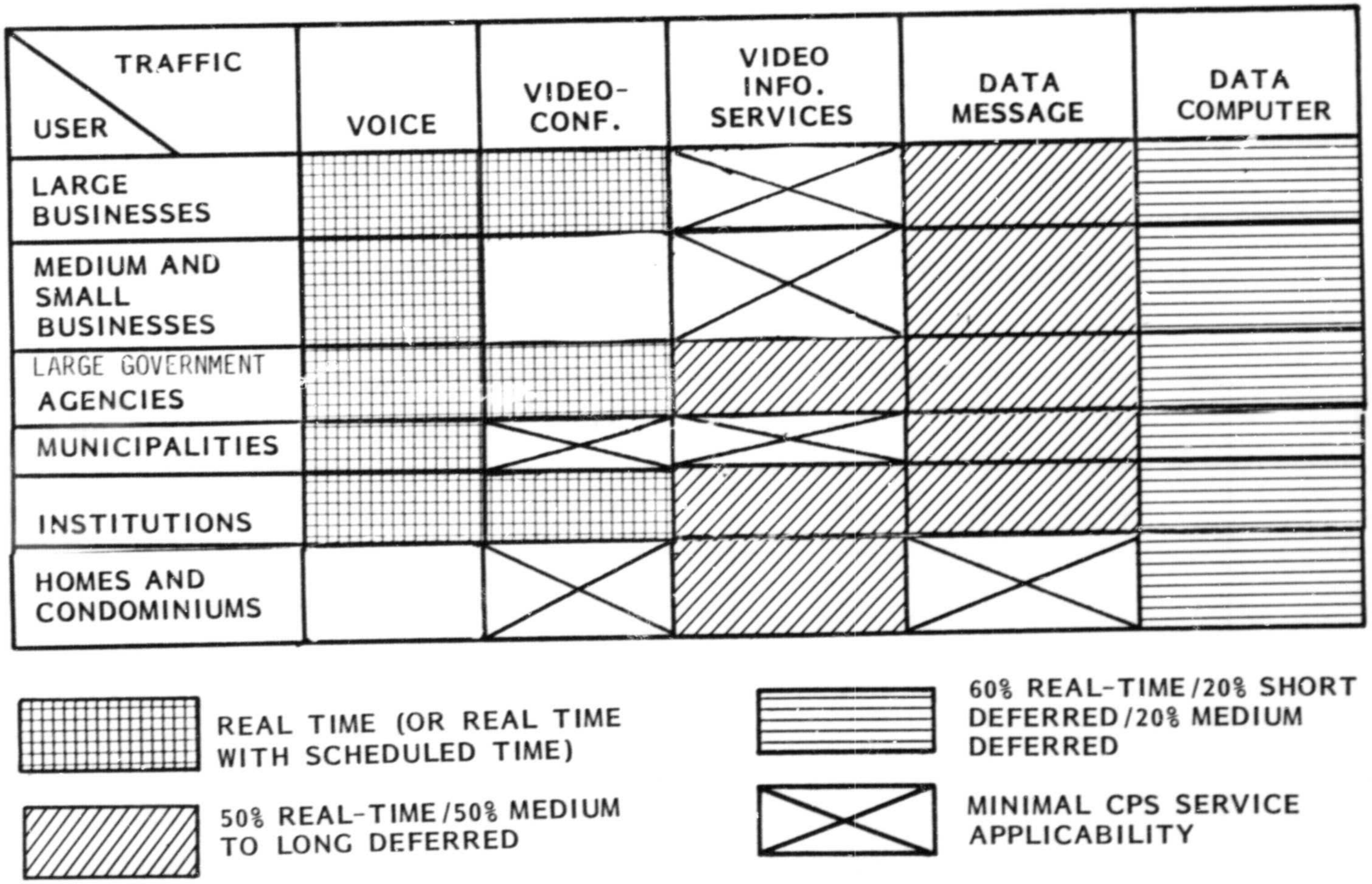


Table 2.3-14. 30/20 GHz CPS Traffic Service Availability - Year 2000

	1	2	3	4
TRAFFIC SERVICE	AT 20% COST PREMIUM 99.99% AVAIL.	REFERENCE COST 99.9% AVAIL.	AT 30% COST REDUCTION 99.5% AVAIL.	AT 35% COST REDUCTION 99.0% AVAIL.
VOICE	5	75	12	8
VIDEO INFORMATION SERVICES	5	50	25	20
VIDEO CONFERENCING	10	50	20	20
DATA MESSAGES*	0	25	0	75
DATA COMPUTER	15	65	10	10

*WEIGHTED AVERAGE OF FACSIMILE & ELECTRONIC MAIL YEAR 2000 TRAFFIC

traffic directionality is given in Table 2.3-15 for service categories and user classes. From Table 2.3-15 (depending on the case) there is a slightly greater inflow of CPS traffic into a given facility than outflow for most of the CPS user classes.

2.4 CPS TRAFFIC DISTRIBUTION

In Section 2.3 the traffic distribution is analyzed in terms of user class and service. In the following section, the distribution of the aggregate traffic over CONUS is analyzed. Included are the geographic distribution of services and users and the range of user and traffic densities per unit area.

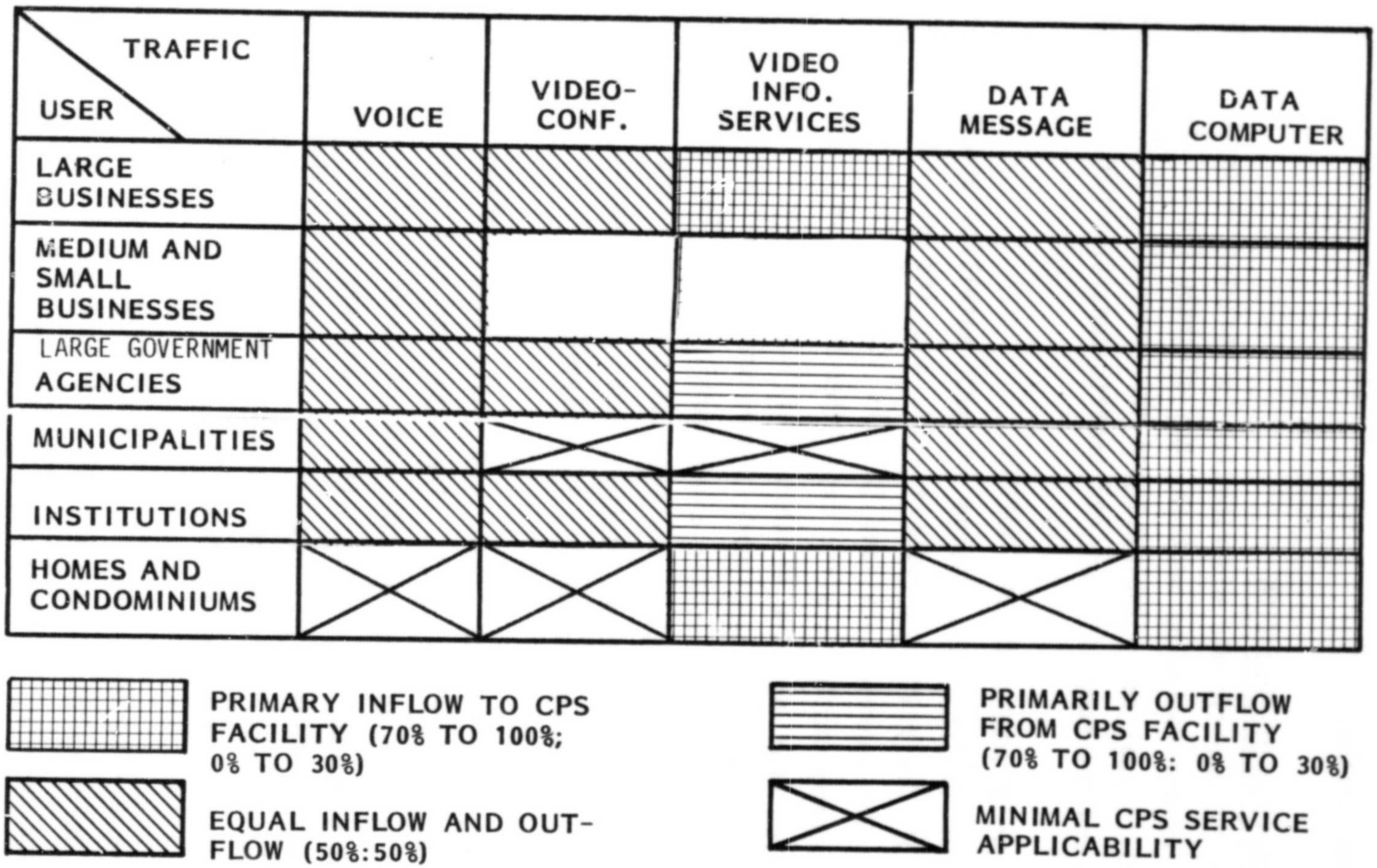
2.4.1 RANGE OF AGGREGATE CPS TRAFFIC

In order to evaluate the design of both satellite and ground networks, an estimate of the peak aggregate traffic and its distribution over CONUS is required. The approach utilized in this study is first to estimate the total long haul communication traffic capacities for the year 1990 and 2000 and then to determine what portion of this traffic is captured by the 30/20 GHz CPS Satellite System. The geographic distribution over CONUS is based on the SMSA and non-SMSA population within a geographic area. For use in satellite system design, this distribution is related to the number and location of satellite beams. For ground network design, the variations in population densities within SMSA's and outside SMSA's is analyzed.

The transmission of the total long haul communication traffic for the year 2000 is shown in Figure 2.4-1. The data used in Figure 2.4-1 is derived from Reference 1 with updates in the area of voice traffic from Reference 3. In determining usage for video, it is assumed that Network TV, CATV, and educational TV (which includes health and public affairs) has 8760 hours/year of transmission. Conferencing assumes two hours/conference and two simplex lines. The uncompressed video channel data rate is 42 Mbps.

In Figure 2.4-1, both the traffic generated by the user and the throughput traffic facility capacity is given. In the data traffic, there is a great difference between the traffic generated and the throughput traffic facility capacity because of large differences in transmission efficiency. The transmission efficiency (ratio of traffic generated by user to throughput facility capacity) for the data services is:

Table 2.3-15. Traffic Directionality Requirements



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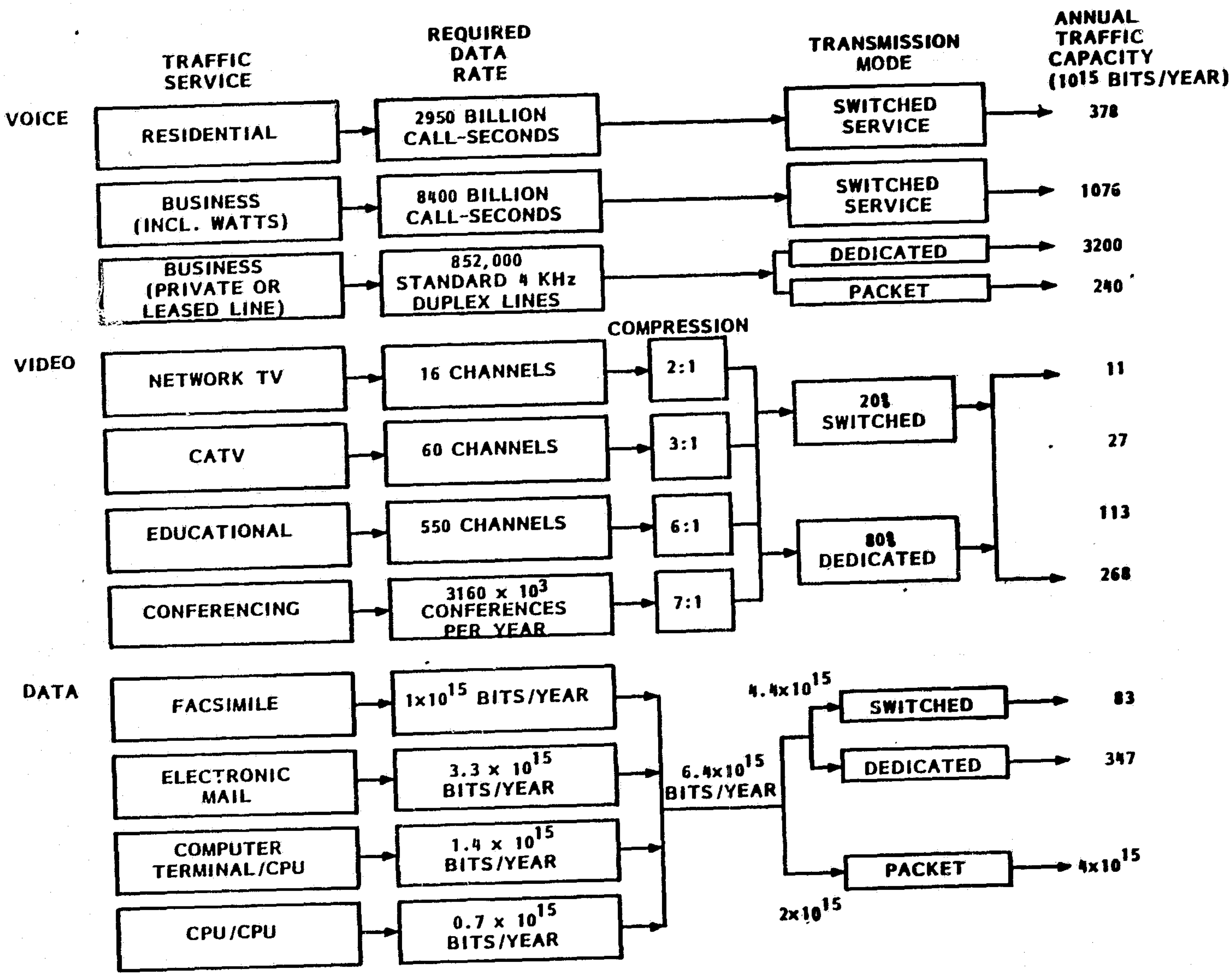


Figure 2.4-1. Transmission of Long Haul Communication Traffic (Year 2000)

Traffic	Transmission Efficiency
Facsimile	0.025
Electronic Mail	0.47
Terminal/CPU	0.0035
CPU/CPU	0.02

The terminal/CPU traffic assumes 20% of traffic utilizing DIAL network (efficiency = 0.005), 20% of traffic by private line (efficiency = (0.001) and the remaining traffic by packet networks (efficiency = 0.5). It should be noted that packet networks services a major fraction of users even though its percentage of total line capacity is small because of its high transmission efficiency. For the year 2000, the packet services have the following relative usage factors:

Initiated Total Data Traffic:	0.3125
Annual Total Data Traffic Facility Capacity:	0.0092

In terms of computer data traffic (non-message traffic) packet data would be representative of more than 40% of the initiated traffic (but only about one percent of computer data facility annual capacity).

In order to determine peak traffic from the annual traffic facility capacities, weighted peak factors for the aggregate traffic for the years 1990 and 2000 are respectively 2.0 and 1.85 (Reference 3, Page 76).

The total long haul annual communication facility capacity and peak traffic capacity for the years 1990 and 2000 (Reference 3) are:

	Year	
	1990	2000
Long Haul Communication Facility Traffic Demand (Bits Per Year x 10^{15})	2701	5747
Peak Long Haul Communication Facility Traffic Capacity (Mbps)	181,000	356,000

Only a small fraction of the above long haul communication traffic is projected to capture the 30/20 GHz (Ka-Band) CPS Satellite market. Figure

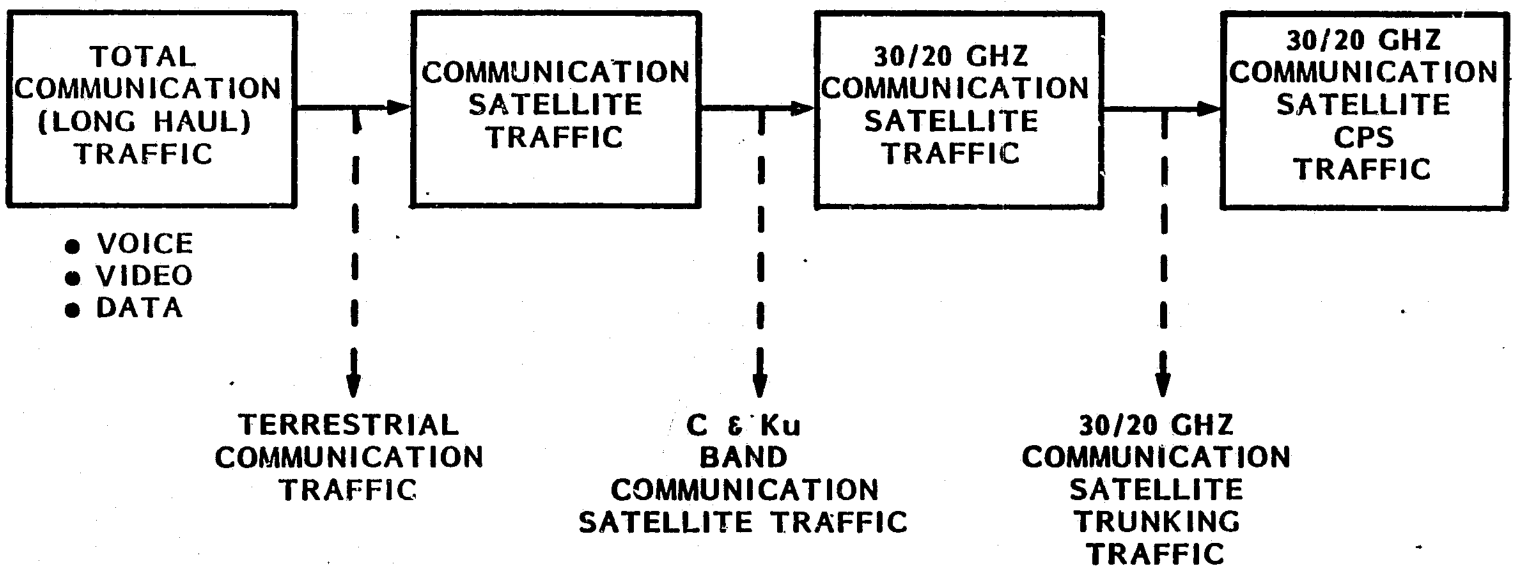
2.4-2 illustrates the competition of the 30/20 GHz Communication Satellite CPS System with other systems: terrestrial systems; C and Ku-Band communication satellites and 30/20 GHz communication satellite trunking traffic. Based on a set of seven scenarios applying to a 30/20 GHz CPS communication satellite system, the aggregate peak capacity for the year 2000 can range between 4000 Mbps to 33,100 Mbps (with values for year 1990 from six to ten percent of the year 2000 capacities) (Reference 3).

A listing of the seven different scenarios employing 30/20 GHz CPS satellite systems and the year 2000 peak capacities is given in Table 2.4-1. The scenarios I to IV utilize the traffic reduction factors from lack of concentration and reliability (outages) which reduce the captured market. The scenarios V to VII, which have back-up systems to minimize outages, have no availability reduction factor. Hence, the CPS aggregate traffic is significantly increased. The growth of the 30/20 GHz CPS satellite traffic from the years 1990 to 2005 is given in Figure 2.4-3. As indicated there the CPS traffic grows at a rate of about 25 percent per year during the interval between the years 1990 and 2000 and tapers off rapidly between the years 2000 and 2005.

2.4.2 GEOGRAPHIC DISTRIBUTION OF 30/20 GHz CPS TRAFFIC

The distribution of the aggregate 30/20 GHz CPS traffic by traffic class groupings and user class is given in Tables 2.3-4 to 2.3-7. The further distribution or division of this traffic over a given region in CONUS is assumed to be proportional to the relative population of the region as compared to the total population covered by the satellite.

Traffic distribution by satellite beam can be developed by assuming the traffic is proportional to the fraction of the total CONUS population residing on the land area covered by the beam. Data on the peak capacity per beam versus number of satellite beams and location of beam in question is presented in the work on the definition of the space segment for the satellite system (Section 4).



YEAR	PEAK CAPACITY
1990	181,000 Mbps
2000	356,000 Mbps

RANGE

YEAR 2000	PEAK CAPACITY
4000 Mbps	TO 33,100 Mbps

YEAR 1990	PEAK CAPACITY
250 Mbps	TO 3424 Mbps

Figure 2.4-2. Aggregate Traffic to 30/20 GHz CPS Satellite Systems

Table 2.4-1. Year 2000 30/20 GHz Satellite System Aggregate Traffic Peak Capacity (Reference 3)

SCENARIO NUMBER	SCENARIO DESCRIPTION	YEAR 2000 CPS PEAK TRAFFIC
I	STANDALONE 30/20 GHz SYSTEM: HIGH RELIABILITY TRUNKING PLUS CPS (LOW RELIABILITY)*	4000
II	30/20 GHz SYSTEM IN COMBINATION WITH TERRESTRIAL FACILITIES: LOW RELIABILITY 30/20 GHz SYSTEM TRUNKING PLUS CPS (LOW RELIABILITY)*	4100
III	30/20 GHz SYSTEM IN COMBINATION WITH TERRESTRIAL FACILITIES: HIGH RELIABILITY 30/20 GHz SYSTEM TRUNKING PLUS CPS (LOW RELIABILITY)*	4100
IV	LOW RELIABILITY 30/20 GHz SYSTEM TRUNKING PLUS CPS (LOW RELIABILITY)* IN COMBINATION WITH C-BAND OR Ku BAND TRUNKING	4100
V	LOW RELIABILITY 30/20 GHz CPS SYSTEM WITH C-BAND OR Ku BAND TRUNKING AND CPS FACILITIES AS BACKUP	33,100
VI	LOW RELIABILITY 30/20 GHz TRUNKING WITH CPS IN COMBINATION WITH C-BAND OR Ku BAND TRUNKING AND CPS FACILITIES (AS BACK-UP)	20,800
VII	HIGH RELIABILITY 30/20 GHz TRUNKING WITH LOWER RELIABILITY CPS IN COMBINATION WITH C-BAND OR Ku BAND CPS (AS BACK-UP)	15,000

* LOW RELIABILITY INFERS NO BACK-UP DUE TO DIVERSITY OR OTHER MEANS

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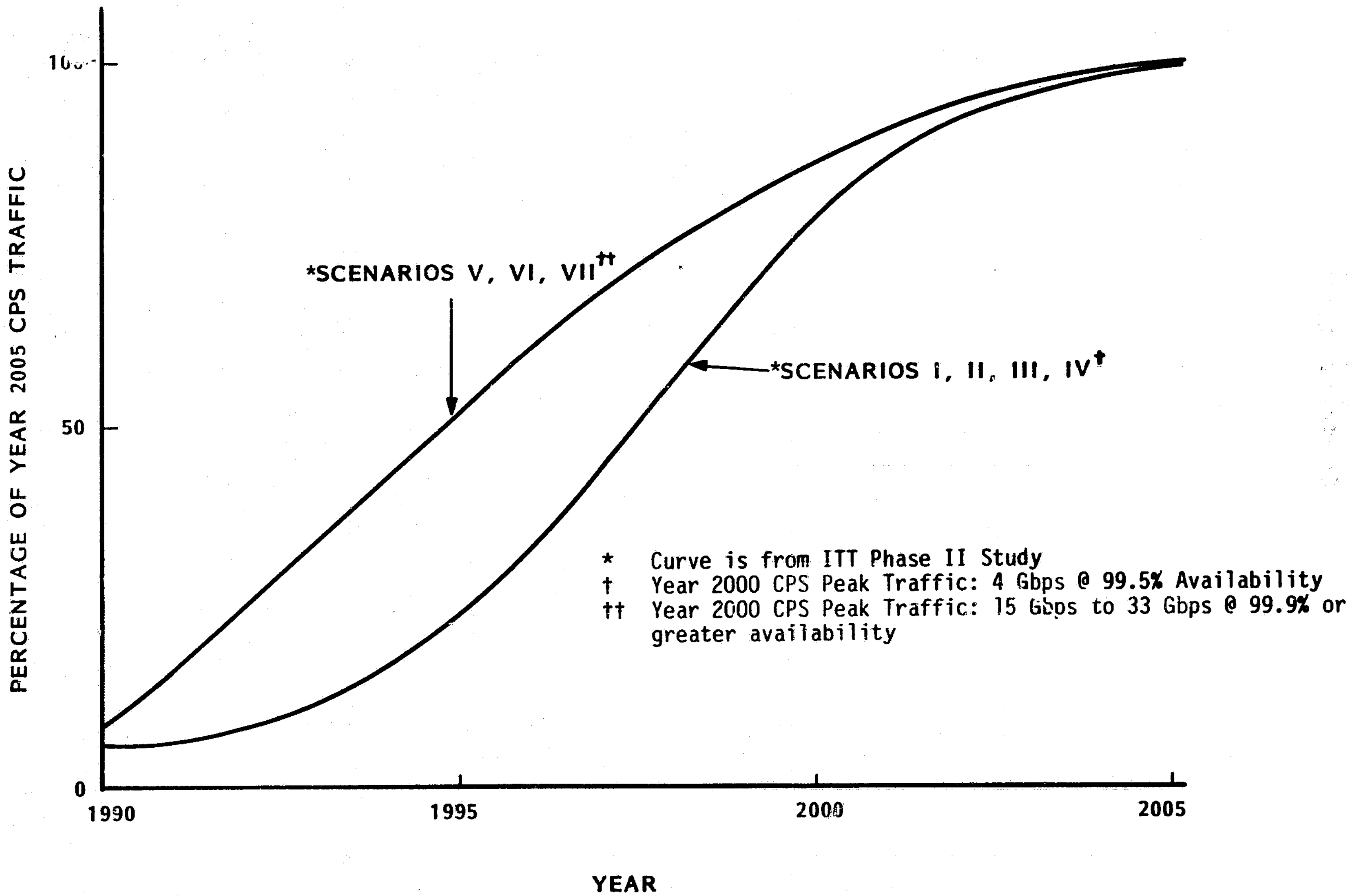

Figure 2.4-3. 30/20 GHz CPS Traffic vs. Year

In order to evaluate the ground networking options the variation in traffic per square kilometer over different user environments is required. A range of traffic densities based on Reference 4 population and land area data, is given in Table 2.4-2 for rural and urban environments and inside and outside SMSA's environments. The traffic densities vary by more than a factor of 100 when urban and rural environments are compared. Outside SMSA's the traffic densities are quite close to that of the rural environment. Inside SMSA's the traffic density is a factor of 10 smaller than that within an urban area but more than 10 times greater than rural area traffic densities. Therefore, a typical SMSA would consist of a relatively small urban area and a much larger suburban and rural segment. The maximum traffic densities within the SMSA would correspond to the urban densities listed in Table 2.4-2.

The variations in traffic density versus region (see Figure 2.4-4 for map defining CONUS regions) is given in Table 2.4-3. Both the traffic density by region and the traffic density for a large metropolitan area within the region is given in Table 2.4-3. The overall urban area traffic densities of Table 2.4-2 correspond to the minimum value of metropolitan area traffic densities of Table 2.4-3. Some of the metropolitan areas with large population densities can have traffic densities ranging from as much as 0.25 Mbps/sq km for aggregate peak traffic of 5000 Mbps to greater than .75 Mbps/sq km for maximum values of aggregate traffic of 15,000 Mbps. The distribution of user class service category densities can be obtained by multiplying the factors given in Tables 2.3-4 to 2.3-7 by the data given in Tables 2.4-2 and 2.4-3.

2.4.3 USER DENSITY DISTRIBUTIONS OVER CONUS

The user density distribution can be estimated using similar assumptions as for estimating traffic densities, in that the user density is proportional to population density. The quantity of user facilities available to CPS, for an aggregate traffic of 5 Gbps was given in Table 2.3-11.

Based on the population data given in Reference 4 and the user data of Table 2.3-11, a summary of User Densities over CONUS is given in Table 2.4-4 and regional user density data is given in Table 2.4-5. The data in Tables 2.4-4 and 2.4-5 is graphically illustrated in the bar charts of Figures 2.4-5 and 2.4-6 for a aggregate traffic of 5 Gbps. For other values of aggregate traffic, these data can be scaled in proportion to the peak aggregate capacity.

Table 2.4-2. Summary of CONUS Traffic Density Variations (Mbps per Square Kilometer)

	AGGREGATE PEAK CAPACITY	
		(MBPS)
	5,000	15,000
ENTIRE CONUS	6.39×10^{-4}	1.92×10^{-3}
URBAN AREAS	2.62×10^{-2}	7.86×10^{-2}
RURAL AREAS	3.42×10^{-3}	4.4×10^{-4}
INSIDE SMSA'S	3.42×10	10.3×10^{-3}
OUTSIDE SMSA'S	1.90×10^{-4}	5.7×10^{-4}

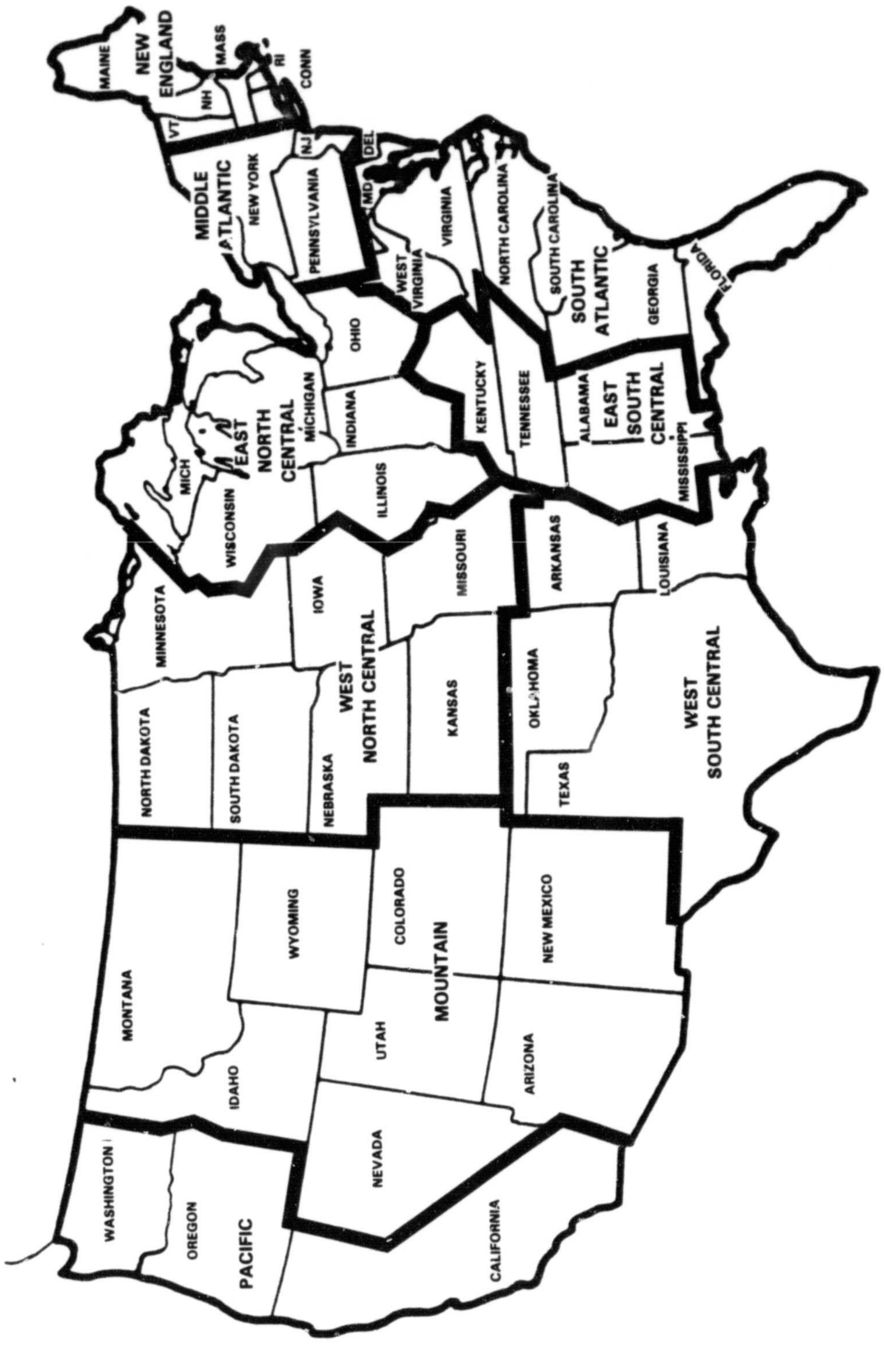

Figure 2.4-4. Geographic Traffic Regions

Table 2.4-3. Traffic Density vs. CONUS Region (Mbps per sq KM)

REGION	REGIONAL TRAFFIC DENSITY AGGREGATE CAPACITY (Mbps) 5000	15000	METROPOLITAN AREA	METROPOLITAN AREA TRAFFIC DENSITY AGGREGATE CAPACITY (Mbps) 5000	15000
NEW ENGLAND	1.79×10^{-3}	5.36×10^{-3}	BOSTON,MASS	0.132	0.397
MIDDLE ATLANTIC	3.53×10^{-3}	1.06×10^{-2}	NEW YORK CITY	0.25	0.751
EAST NORTH CENTRAL	1.57×10^{-3}	4.7×10^{-3}	CHICAGO,ILL.	0.144	0.431
WEST NORTH CENTRAL	3.05×10^{-4}	9.14×10^{-4}	ST.LOUIS,MO.	0.0965	0.290
SOUTH ATLANTIC	1.09×10^{-3}	3.27×10^{-3}	ATLANTA,GA.	0.0359	0.108
EAST SOUTH CENTRAL	6.79×10^{-4}	2.04×10^{-3}	LOUISVILLE,KY.	0.0572	0.172
WEST SOUTH CENTRAL	4.29×10^{-4}	1.29×10^{-3}	HOUSTON,TEX.	0.0270	0.0809
MOUNTAIN	9.21×10^{-5}	2.76×10^{-4}	PHOENIX,ARIZ.	0.0223	0.068
PACIFIC	7.8×10^{-4}	2.3×10^{-3}	LOS ANGELES,CA.	0.0577	0.173

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Table 2.4-4. Conus CPS User Facility Densities (Facilities Per Sq. Km)
Year 2000 Peak Aggregate Capacity 5000 Mbps

	USER CLASS	ENTIRE CONUS	URBAN	RURAL	INSIDE SMSA'S	OUTSIDE SMSA's
AVAILABILITY = 99.5%	LARGE BUSINESS	$6x10^{-5}$	$2.5x10^{-3}$	$1.4x10^{-5}$	$3.2x10^{-4}$	$1.8x10^{-5}$
	MEDIUM/SMALL BUSINESS	$1x10^{-4}$	$4.1x10^{-3}$	$2.3x10^{-5}$	$5.4x10^{-4}$	$3x10^{-5}$
	LARGE GOVERNMENT AGENCIES	$3.5x10^{-6}$	$1.4x10^{-4}$	$8.1x10^{-7}$	$1.9x10^{-5}$	$1x10^{-6}$
	MUNICIPALITIES	$2.2x10^{-5}$	$9x10^{-4}$	$5.1x10^{-6}$	$1.2x10^{-4}$	$6.5x10^{-6}$
	INSTITUTIONS (AVG)	$1.4x10^{-5}$	$5.7x10^{-4}$	$3.2x10^{-6}$	$7.5x10^{-5}$	$4.2x10^{-6}$
	PRIVATE HOMES, CONDOMINIUMS CONCENTRATION 1000:1	$3.2x10^{-6}$	$1.3x10^{-4}$	$7.4x10^{-7}$	$1.7x10^{-5}$	$9.5x10^{-7}$
	TOTAL FACILITIES	$2x10^{-4}$	$8.2x10^{-3}$	$4.6x10^{-5}$	$1.1x10^{-3}$	$5.9x10^{-5}$
AVAILABILITY = 99.9%	LARGE BUSINESS	$5.2x10^{-5}$	$2.1x10^{-3}$	$1.2x10^{-5}$	$2.8x10^{-4}$	$1.5x10^{-5}$
	MEDIUM/SMALL BUSINESS	$8x10^{-5}$	$3.3x10^{-3}$	$1.8x10^{-5}$	$4.3x10^{-4}$	$2.4x10^{-5}$
	LARGE GOVERNMENT AGENCIES	$3.1x10^{-6}$	$1.3x10^{-4}$	$7.1x10^{-7}$	$1.7x10^{-5}$	$9.2x10^{-7}$
	MUNICIPALITIES	$1.8x10^{-5}$	$7.4x10^{-4}$	$4.1x10^{-6}$	$9.6x10^{-5}$	$5.4x10^{-6}$
	INSTITUTIONS (AVG)	$1.4x10^{-5}$	$5.7x10^{-4}$	$3.2x10^{-6}$	$7.5x10^{-5}$	$4.2x10^{-6}$
	PRIVATE HOMES, CONDOMINIUMS CONCENTRATION 1000:1	$3.2x10^{-6}$	$1.3x10^{-4}$	$7.4x10^{-7}$	$1.7x10^{-5}$	$9.5x10^{-7}$
	TOTAL FACILITIES	$1.7x10^{-4}$	$7x10^{-3}$	$3.9x10^{-5}$	$9.1x10^{-4}$	$5.1x10^{-5}$

Table 2.4-5. Metropolitan/Regional CPS User Facility Densities (Facilities Per Sq. Km) Year 2000 Peak Aggregate Capacity 5000 Mbps

AVAILABILITY 99.5%

USER REGION/METROPOLITAN AREA	LARGE BUSINESS	SMALL/MEDIUM BUSINESS	LARGE GOVERNMENT AGENCIES	MUNICIPALITIES*	INSTITUTIONS	PRIVATE HOMES & CONDOS 1000:1
NEW ENGLAND	1.7×10^{-4}	2.8×10^{-4}	9.8×10^{-6}	6.1×10^{-5}	3.9×10^{-5}	8.9×10^{-6}
BOSTON	1.3×10^{-2}	2.1×10^{-2}	7.3×10^{-4}	4.5×10^{-3}	2.9×10^{-3}	6.6×10^{-4}
MIDDLE ATLANTIC	3.3×10^{-4}	5.5×10^{-4}	1.9×10^{-5}	1.2×10^{-4}	7.7×10^{-5}	1.8×10^{-5}
NEW YORK CITY	2.3×10^{-2}	3.9×10^{-2}	1.3×10^{-3}	8.5×10^{-3}	5.5×10^{-3}	1.3×10^{-3}
EAST NORTH CENTRAL	1.5×10^{-9}	2.5×10^{-4}	8.6×10^{-6}	5.4×10^{-5}	3.4×10^{-5}	7.8×10^{-6}
CHICAGO	1.4×10^{-2}	2.3×10^{-2}	7.9×10^{-4}	5×10^{-3}	3.1×10^{-3}	7.2×10^{-4}
WEST NORTH CENTRAL	2.9×10^{-5}	4.8×10^{-5}	1.7×10^{-6}	1×10^{-5}	6.7×10^{-6}	1.5×10^{-6}
ST. LOUIS	9.2×10^{-3}	1.5×10^{-2}	5.4×10^{-4}	3.2×10^{-3}	2.1×10^{-3}	4.8×10^{-4}
SOUTH ATLANTIC	1×10^{-4}	1.7×10^{-4}	6×10^{-6}	3.8×10^{-5}	1.3×10^{-5}	5.5×10^{-6}
ATLANTA	3.3×10^{-3}	5.6×10^{-3}	2×10^{-4}	1.2×10^{-3}	7.9×10^{-4}	1.8×10^{-4}
EAST SOUTH CENTRAL	6.4×10^{-5}	1.1×10^{-4}	3.7×10^{-6}	2.3×10^{-5}	1.5×10^{-5}	3.4×10^{-6}
LOUISVILLE	5.4×10^{-3}	9.3×10^{-3}	3.1×10^{-4}	1.9×10^{-3}	1.3×10^{-3}	2.9×10^{-4}
WEST SOUTH CENTRAL	4×10^{-5}	6.7×10^{-5}	2.4×10^{-6}	1.5×10^{-5}	9.4×10^{-6}	2.1×10^{-6}
HOUSTON	2.5×10^{-3}	4.2×10^{-3}	1.5×10^{-4}	9.4×10^{-4}	5.9×10^{-4}	1.3×10^{-4}
MOUNTAIN	8.6×10^{-6}	1.4×10^{-5}	5×10^{-7}	3.2×10^{-6}	2×10^{-6}	4.6×10^{-7}
PHOENIX	2.1×10^{-3}	3.4×10^{-3}	1.2×10^{-5}	7.7×10^{-4}	4.8×10^{-4}	1.1×10^{-4}
PACIFIC	7.3×10^{-5}	1.2×10^{-4}	4.3×10^{-6}	2.7×10^{-5}	1.7×10^{-5}	3.9×10^{-6}
LOS ANGELES	5.4×10^{-3}	8.9×10^{-3}	3.2×10^{-4}	2×10^{-3}	1.3×10^{-3}	2.9×10^{-4}

AVAILABILITY 99.9%

USER REGION/METROPOLITAN AREA	LARGE BUSINESS	SMALL/MEDIUM BUSINESS	LARGE GOVERNMENT AGENCIES	MUNICIPALITIES*	INSTITUTIONS	PRIVATE HOMES & CONDOS 1000:1
NEW ENGLAND	1.5×10^{-4}	2.2×10^{-4}	8.7×10^{-6}	5×10^{-5}	3.9×10^{-5}	8.9×10^{-6}
BOSTON	1.1×10^{-2}	1.6×10^{-3}	6.4×10^{-4}	3.7×10^{-3}	2.9×10^{-3}	6.6×10^{-4}
MIDDLE ATLANTIC	2.9×10^{-4}	4.4×10^{-4}	1.7×10^{-5}	9.9×10^{-5}	7.7×10^{-5}	1.8×10^{-5}
NEW YORK CITY	2.1×10^{-2}	3.1×10^{-2}	1.2×10^{-3}	7×10^{-3}	5.5×10^{-3}	1.3×10^{-3}
EAST NORTH CENTRAL	1.3×10^{-4}	2×10^{-4}	7.6×10^{-6}	4.4×10^{-5}	3.4×10^{-5}	7.8×10^{-6}
CHICAGO	1.2×10^{-2}	1.8×10^{-2}	7×10^{-4}	4×10^{-3}	3.1×10^{-3}	7.2×10^{-4}
WEST NORTH CENTRAL	2.5×10^{-5}	3.8×10^{-5}	1.5×10^{-6}	8.6×10^{-6}	6.7×10^{-6}	1.5×10^{-6}
ST. LOUIS	7.9×10^{-3}	1.2×10^{-2}	4.8×10^{-4}	2.7×10^{-3}	2.1×10^{-3}	4.8×10^{-4}
SOUTH ATLANTIC	8.9×10^{-5}	1.4×10^{-4}	5.3×10^{-6}	3.1×10^{-5}	2.4×10^{-5}	5.5×10^{-6}
ATLANTA	2.9×10^{-3}	4.6×10^{-3}	1.7×10^{-4}	1×10^{-3}	7.9×10^{-4}	1.8×10^{-4}
EAST SOUTH CENTRAL	5.5×10^{-5}	8.5×10^{-5}	3.3×10^{-6}	1.3×10^{-5}	1.5×10^{-5}	3.4×10^{-6}
LOUISVILLE	4.6×10^{-3}	7.2×10^{-3}	2.8×10^{-4}	1.6×10^{-3}	1.3×10^{-3}	2.9×10^{-4}
WEST SOUTH CENTRAL	3.5×10^{-5}	5.4×10^{-5}	2.1×10^{-6}	1.2×10^{-5}	9.4×10^{-6}	2.1×10^{-6}
HOUSTON	2.2×10^{-3}	3.4×10^{-3}	1.3×10^{-4}	5.9×10^{-4}	4.6×10^{-4}	1.3×10^{-4}
MOUNTAIN	7.5×10^{-6}	1.2×10^{-5}	4.5×10^{-7}	2.6×10^{-6}	2×10^{-6}	4.6×10^{-7}
PHOENIX	1.8×10^{-3}	2.9×10^{-3}	1.1×10^{-4}	6.3×10^{-4}	4.8×10^{-4}	1.1×10^{-4}
PACIFIC	6.4×10^{-5}	9.8×10^{-5}	3.8×10^{-6}	2.2×10^{-5}	1.7×10^{-5}	3.9×10^{-6}
LOS ANGELES	4.7×10^{-3}	7.2×10^{-3}	2.8×10^{-4}	1.6×10^{-3}	1.3×10^{-3}	2.9×10^{-4}

* MUNICIPALITIES ARE SPREAD WITHIN REGION AND NOT WITHIN METROPOLITAN AREA

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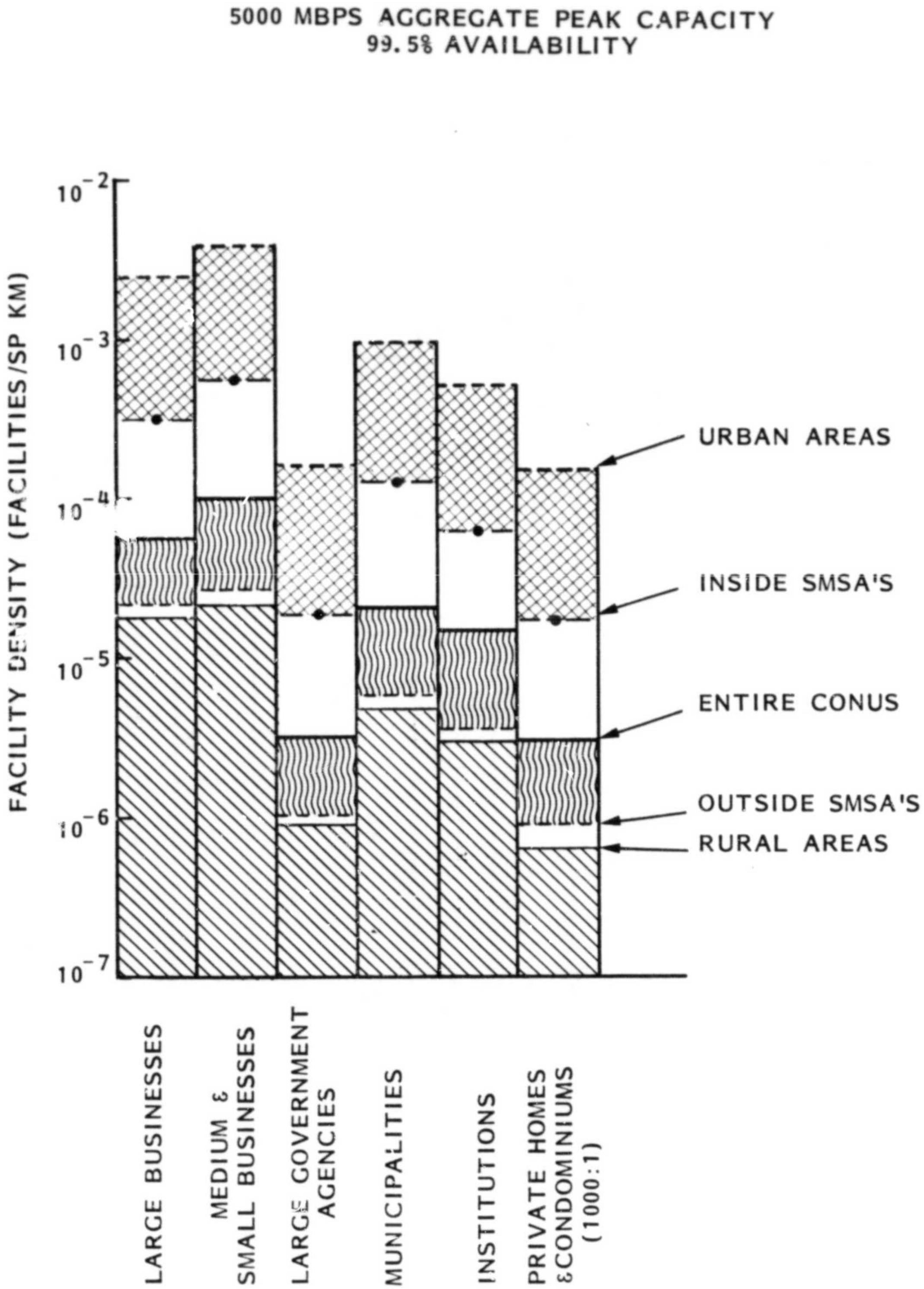

Figure 2. 5. CONUS CPS User Facility Densities 5000 Mbps Aggregate Peak Capacity (Availability 99.5%)

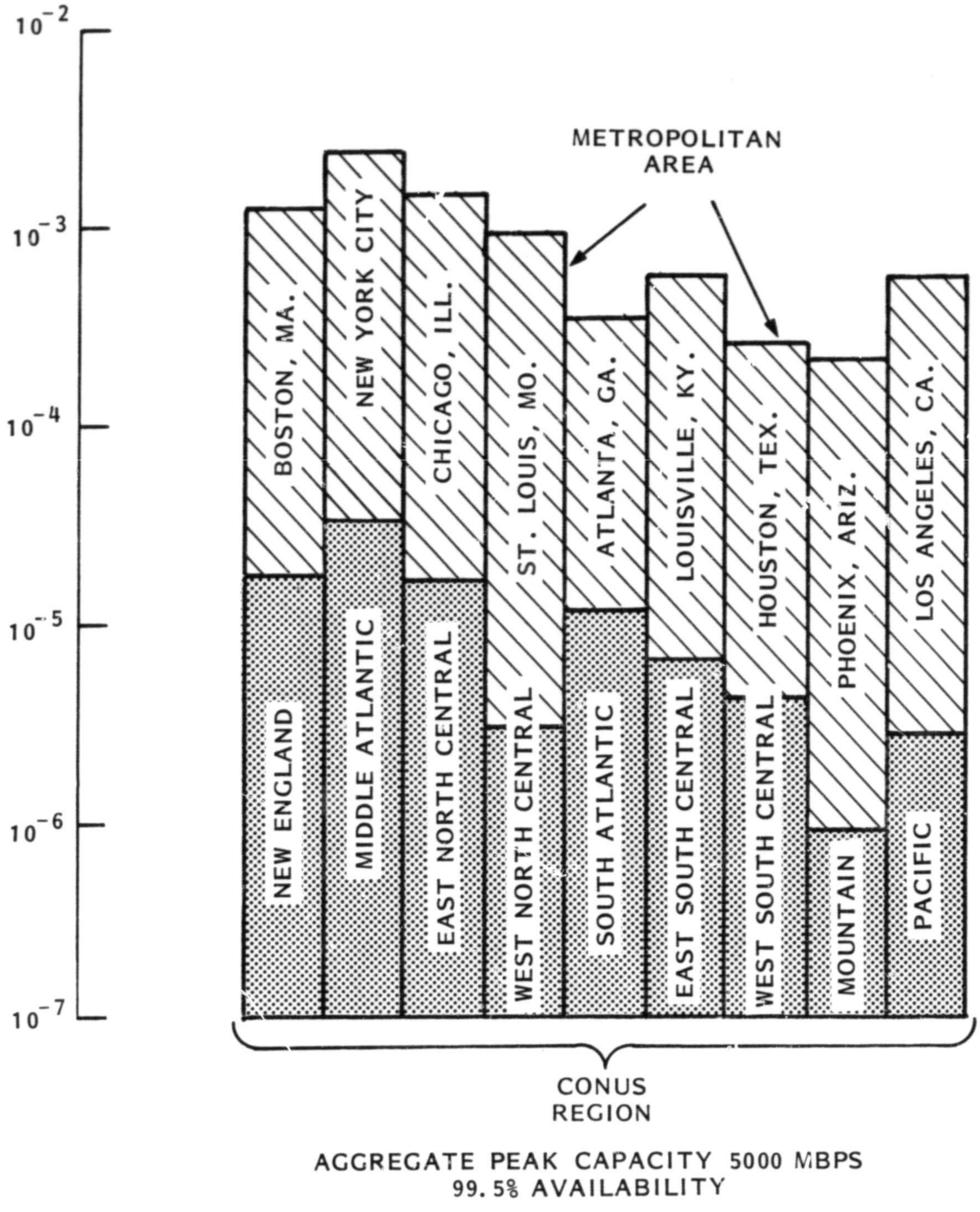

Figure 2.4-6. Metropolitan/Regional CPS User Facility Densities
Aggregate Peak Capacity: 5000 Mbps User Class:
Large Businesses (Availability 99.5%)

The results in Figure 2.4-5 apply only to the case of a peak aggregate capacity of 5 Gbps. The results in Figure 2.4-6 are for the case of large business users. It is apparent from these data that the major users of CPS are concentrated within the urban areas.

The spacing between members of a given user class is useful in evaluation of ground networking options. Table 2.4-6 presents the range of maximum and minimum spacings per user class facility versus aggregate capacity and user class based on the data of Table 2.4-5. In determining the spacing between user facilities, it is assumed that municipalities are spaced only within a regional area. Also, from the range of spacings, it appears that Federal Agencies and Large State and City Agencies have only one CPS facility per given metropolitan area. Therefore, the regional spacings are more representative of these user classes.

For very large metropolitan areas, there are more than one institution using CPS but the average spacings are relatively large. Large, medium and small business CPS facilities have relatively small spacings per user facility within a metropolitan area.

2.5 SUMMARY

A summary of CPS service offerings is given in Table 2.5-1.

In addition the requirements for these offerings have been identified (availability, waiting time, bit error rate).

In Section 2.4 the traffic distribution is analyzed. Based on likely scenarios for CPS, the range of aggregate peak traffic for the year 2000 is probably between 56 Gbps and 15 Gbps. However, for very unfavorable conditions, or very favorable conditions, the capacity can be as low as 3 Gbps or as high as 30 Gbps.

Table 2.4-6. Range of Mean Spacings Between User Class Facilities (KM)

USER CLASS	AGGREGATE CAPACITY 5000 MBPS REGIONAL AREA	5000 MBPS METROPOLITAN AREA	15,000 MBPS REGIONAL AREA	15,000 MBPS METROPOLITAN AREA
LARGE BUSINESS	55 TO 340	7 TO 22	32 TO 196	4 TO 13
MEDIUM & SMALL BUSINESS	43 TO 267	5 TO 17	25 TO 101	3 TO 10
LARGE GOVERNMENT AGENCIES**	229 TO 1414	28 TO 91**	132 TO 816	16 TO 53 **
MUNICIPALITIES*	91 TO 5[illegible]	----	53 TO 323	----
INSTITUTIONS	114 TO 707	14 TO 46	66 TO 408	8 TO 27
PRIVATE HOMES & CONDOS (GROUPS OF 1000 HOUSEHOLDS)	236 TO 1474	28 TO 95	136 TO 851	16 TO 55

* MUNICIPALITIES ARE ASSUMED TO BE SPACED ONLY WITHIN REGIONAL AREAS AND NOT METROPOLITAN

** PROBABLY ONLY ONE CPS FACILITY IN A METROPOLITAN AREA

AVAILABILITY OF 99.5% (approximately same for availability 99.9%)

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Table 2.5-1. CPS Service Offerings

CPS SERVICE	PRINCIPAL TRAFFIC CLASSES	USERS IN ORDER OF TOTAL TRAFFIC	RELATIVE SHARE OF MARKET		CPS CHARACTERISTICS
			avail. 99.5%	avail. 99.9%	
VOICE	TELEPHONE NARROW BAND TELECONFERENCING	•BUSINESS •GOVERNMENT •INSTITUTIONS •PRIVATE	34.7%	40.8%	•64KBPS TRANSMISSION RATE •MULTIPLE TRUNKS/USER •SECONDS WAITING TIME •HIGH AVAILABILITY
VIDEO CONFERENCING	VIDEO CONFERENCING	•BUSINESS •INSTITUTIONS •GOVERNMENT	37.8%	33.5%	• 2T1 TWO WAY TRANSMISSION RATE •POINT TO POINT TRANSMISSION •SCHEDULED •AVAILABILITY TO MEET SCHEDULE
VIDEO INFORMATION SERVICE	INFORMATION SERVICES	•INSTITUTIONS •GOVERNMENT •PRIVATE	20%	19.4%	• 4T1 TRANSMISSION RATE •ONE TRUNK/USER •SECOND TO 1 DAY WAITING TIME •LOW TO HIGH AVAILABILITY
DATA MESSAGES	ELECTRONIC MAIL DOCUMENT COMMUNICATIONS	•BUSINESS •GOVERNMENT •INSTITUTIONS	3.2%	2.8%	•DATA RATES in units of 56KBPS •ONE TO MULTIPLE TRUNKS/USER •SECONDS TO HOURS WAITING TIME •LOW TO HIGH AVAILABILITY
DATA COMPUTER	ELECTRONIC FUND TRANSFER POINT OF SALE COMPUTER-TO-COMPUTER COMMUNICATIONS LIBRARY SEARCH, QUERY, AND RESPONSE RESERVATION DATA GENERAL DATA COLLECTION AND TRANSFER SERVICES SECURE VOICE COMMUNICATIONS COMMAND AND CONTROL AUTOMATIC BILLING SERVICES	•BUSINESSS •GOVERNMENT •INSTITUTIONS •PRIVATE	4.3%	3.5%	•DATA RATES ≤9.6 KBPS EXCEPT FOR BULK TRANSFER •PRINCIPALLY SHARED SERVICE •SECONDS TO MINUTES WAITING TIME •HIGH AVAILABILITY

* Based on Peak Throughput Capacity of CPS System for Year 2000

An evaluation of traffic classes and user classes is presented in Sections 2.1 and 2.2. From this evaluation a range of CPS service offerings have been identified in Section 2.3. These can be divided into groupings:

Group	User Class	Services Offered
I	Large Businesses Federal Agencies Large State and City Agencies	Voice Video-conferencing Data Message and Computer (Large Businesses Can be offered Video Information Services if Concentration Provided)
II	Institutions	Voice Video-conferencing Video-Information Data Message and Computer
III	Municipalities Medium and Small Businesses	Voice Data Message and Computer (Medium and Small Business can be offered both Video Services if Concentration Provided)
IV	Private Homes and Condos	Data Computer (Can be offered Video Information Services if greater Concentration is provided)

Based on the user facility characteristics evaluated in Section 2.2 and the traffic grouping characteristics determined in Section 2.3, the traffic density and user density distributions over CONUS have been computed for the range of aggregate peak traffic between 5 Gbps and 15 Gbps.

From the user densities, the mean spacing per user facility has been determined.

The user group facilities are characterized as follows:

User Class	Distribution Characteristics
Large Businesses Medium and Small Businesses	Relatively Small Spacing, Concentration Can Likely be Employed
Federal Agencies Large State and City Agencies Municipalities	Relatively Large Spacings, Concentration Unlikely Between Facilities
Institutions	Intermediate Spacings, Minimal Concentration Required by Service Offerings
Private Homes and Condominiums	Relatively Small Spacings, Concentration Must Be Employed

C-2

2.6 REFERENCES

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SECTION 3

~~TASK~~ 2 - DEFINITION OF CPS GROUND SEGMENT FOR SATELLITE SYSTEM

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SECTION 3

TASK 2 - DEFINITION OF CPS GROUND SEGMENT FOR SATELLITE SYSTEM

3.1 IDENTIFICATION AND ASSESSMENT OF CPS USER GROUND NETWORKING OPTIONS

The purpose of Section 3.1 is to identify, describe, compare, and contrast the regional communications alternatives for wideband communication between Customer Premise Service earth stations and subscribers located off the earth station premises.

In general, the regional distribution problem may be approached in two very different ways. The first is called the case-by-case approach. In this approach, each service order which is received initiates a set of actions. These actions include evaluating the viable regional distribution alternatives in the regional data base, selecting the optimum alternative, and implementing this alternative and adding it to the data base of "in-place plant."

The second approach is called the area service approach. This approach calls for traffic and service models to be projected some years into the future. An optimal system is then designed to carry the projected traffic. Implementation may take place in advance of actual service requirements. In a general way, this is the approach necessarily used in this study.

The case-by-case approach has two major advantages. First, the heavy initial investment required by the area service approach is avoided, since the case-by-case approach involves "pay as you go" construction, yielding revenue relatively quick. The second advantage of the case-by-case approach is that no traffic forecasting is required.

This eliminates a costly and perilous step in network design, since a system which has been optimized for a given traffic model is not necessarily optimum for any other traffic model. Finally, the eventual result of applying the case-by-case approach is likely to be the equivalent of an area service network.

The area service approach has a different set of advantages. First, the network's growth is more predictable, as opposed to the random growth under the case-by-case approach. This means that planning for operations and maintenance can be done systematically, in advance of actual requirements.

The predictable growth of the area service network simplifies accurate network recordkeeping and documentation. The area service network also encourages growth where the network facilities exist, thereby providing reinforcing feedback to the planning process.

Subscriber charges for service in an area service network tend to be more equitable, as they are more universally shared. This contrasts with the case-by-case network approach, where every installation is a special build, involving special construction fees. This characteristic of the case-by-case approach may serve to discourage growth by what amounts to counter-incentives.

Finally, installation delays are usually shorter under the area service approach than under the case-by-case approach. This feature tends to remove a possible disincentive of the case-by-case approach. Figure 3.1-1 demonstrates the logical steps needed to implement a network. For the area service approach this must be done only once, but for the case-by-case approach, such a course of action must be taken for each new subscriber.

3.1.1 IMPACT OF USER ENVIRONMENT ON CPS GROUND NETWORKING

Extensive knowledge of end user characteristics and requirements is essential to the selection of an appropriate ground networking architecture, including user configurations, specific communications requirements for these configurations, local area networking schemes, and geographic distribution of users. These have been developed by user class and discussed in previous sections of this report. The influence of these factors on the ground networking are discussed here.

Typical CPS Users

The user categories which represent the potential subscribers to the 30/20 GHz CPS network are identified in Section 2.2. The breakdown of projected communications requirements for each user class in the year 2000 is presented in Section 2.3. These data plac~ bounds on the expected traffic levels per location but do not give an indication as to the local area networking scheme chosen by each user. It would appear that most user classes will require intra-building or campus type networking. In this way, the ground networking interface has been moved from the terminal level to the local area network level. This implies that preconcentration of data will occur before the

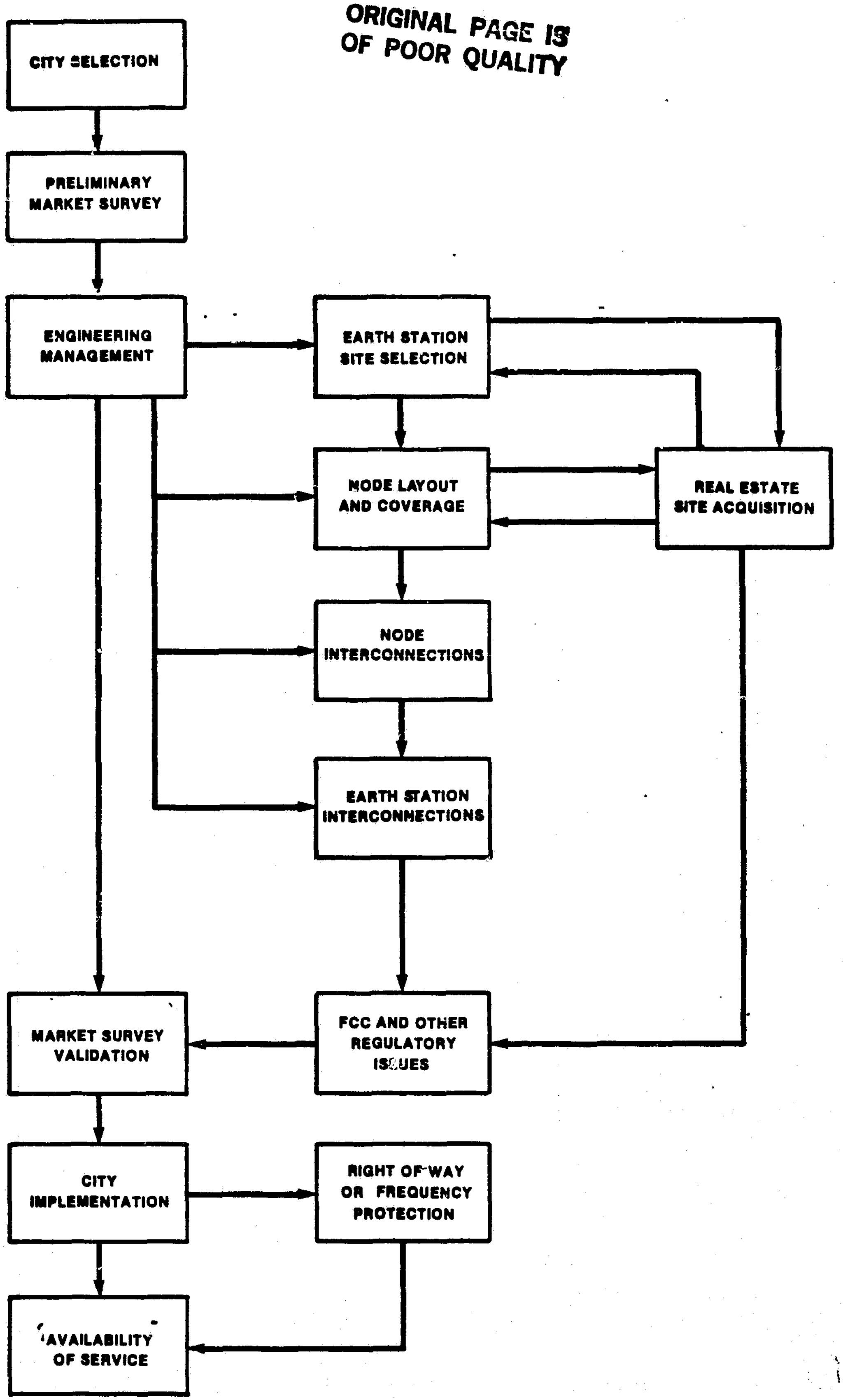

Figure 3.1-1. Program Flow For City Layout

interface to the ground network which means that users take advantage of the bursty nature of their messages to concentrate several terminals per channel in their local area network. This approach will produce a fairly non-bursty subscriber input to the ground network, with little opportunity for further concentration.

However, some of the classes identified that have low enough terminal populations that preconcentration is not possible. A more complete discussion of the system implications of concentration may be found in the following discussion.

Another important input to the formulation of ground networking recommendations is an indication of service applications that each user class requires, as well as performance expectations for those services. This is sufficient for the earth station and space segment design, as it is expected that traffic will be digital. However, the ground network may include some analog transmission requirements, particularly in the case of a shared use video codec. It may be that these codecs will remain relatively expensive and that the best way to provide video conferencing will be via a shared use codec at the CPS earth station.

Impact of Concentration and Local Area Networking Technologies

Concentration in this sense refers to enabling several terminal devices to access the same communication resource. This becomes possible when the terminals involved are bursty sources. This concentration can be performed at any or all of the interfaces encountered, from terminal device to CPS station.

Concentration can have a profound impact upon the type of ground networking architecture. Two polar examples of concentration are the ground network performs no concentration, or the ground network performs nearly all concentration.

In the first scenario, all users will have concentrated their traffic to produce an aggregate output. This output has a total capacity which is consistent with the desired availability and blocking requirements. The second scenario, on the opposite side of the spectrum, would include a multitude of non-associated users, each with low rate outputs and no requirement for full time circuits. If the communications resource is

accessible to all users, each capable of requesting capacity as required, the medium acts as the concentrator. Note that TDMA is a cost effective alternative for this case, as single channel frequency selective modems, required by an FDMA approach, become quite expensive.

A propitious solution may be a hybrid of the two polar strategies. In this configuration, the locations with large aggregate outputs would have point-to-point links connecting them to the earth station; these points would also serve as concentration hubs for the lower rate subscribers.

Certainly most of the user categories mentioned have substantial requirements for internal data routing, so as to have installed a local network within the confines of their plants. These networks are capable of outputting data at either the port or multiplexed level.

One school of thought favors allowing inputs to the local network only at the port level. The logic is that, due to the proliferation of multiplexing standards, any interface other than at the user port level would produce a network for which routing would become a nightmare.

The opposing theory is that inputs to the CPS station should be allowed to be multiplexed to the extent that input ports are assigned specific destinations in the satellite network. This makes for a reasonably rational baseband algorithm and processor for the two primary space segment alternatives: SCPC and TDMA. The motivating factors behind this theory are that most subscribers require connections to their own facilities and hardware for a large majority of the time. In this mode, the scheme of multiplexing becomes transparent to the spacecraft as the networking (concentration, muxing, and routing) functions are performed by the subscriber.

The primary types of local area networks to which the CPS ground network will need to interface include digital PBX, ETHERNET type contention busses, and Token bus type networks. Of these, only digital PBXs can function unaided as an interface to the ground network. The interface can either be provided as a T1 format multiplexed stream of data and voice, or at the 64 kbps voice port level.

Due to the random access protocol of ETHERNET type local area networks, some type of interface processor will be required. This processor must perform several functions, including providing buffering in the outbound direction when the number of outbound packets exceeds the channel capacity available to access the CPS station, providing buffering in the inbound direction so that messages can be queued up when the network is heavily loaded, and providing format and address translation.

To date, no commercial token bus architectures have been produced. Should they become a factor in the local area network market, it would appear that interface processors similar to the one described above would be called for.

Impact of User Distribution on Ground Networking Architectures

Analytical results to date do not give a strong indication as to the topology of the distribution of CPS subscribers. As the possible permutations of user distribution are seemingly endless, there is no reason to expect that any definite identification of user distribution is possible. However, what can be provided is an identification of potential distributions which can be employed parametrically.

Four classes of distribution can be used to describe a great many urban areas. These configurations are a result of geographic location, geographic topology, or highway topology. Figure 3.1-2 is a graphic representation of the four distributions which are beltway community, littoral community, uniformly distributed community, and linear community.

A regular (straight line) distribution would invite guided media solutions (i.e., along a highway which has available duct space or pole space).

Clusters of users interspersed around a city imply a hub style of network. Local concentration could be performed within each cluster, and a point-to-point link would be set up to connect the cluster's concentrated output to the earth station. A natural cluster radius would be that for which guided media may operate without repeaters.

Totally homogeneous distribution of firms would tend to imply a cellular radio approach, as the cost for routing guided media would be at a maximum in this case. This distribution is used in the ground network cost model.

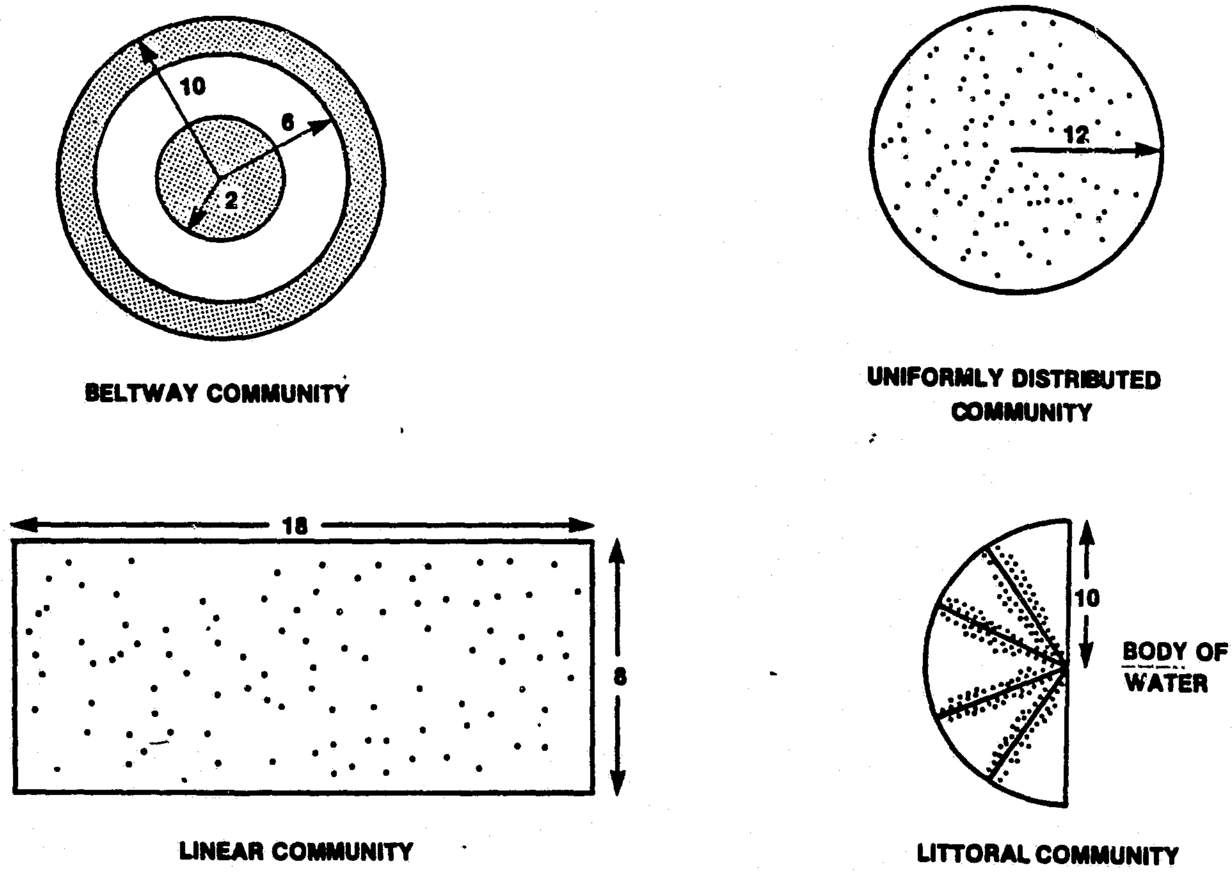

Figure 3.1-2. Examples of Urban Area User Distributions

Impact of Environment on CPS Ground Network Architecture Selection

Technological limitations are not the only ones placed upon a ground networking options. There are regulatory and competitive factors which come to bear upon the selection process as well. One such factor is the degree to which guided media (particularly coaxial cable) have penetrated the area. This could lead to using coaxial cable as the ground networking medium provided that the plant has bi-directional hardware, that the electrical and physical maintenance is of superior quality, and the franchise operator is willing to participate at reasonable rates.

Additionally, the regulatory environment surrounding the provision of enhanced digital services over coaxial cable is at this point an open question. As most CATV systems lie entirely within one state, they may be in the jurisdiction of the state's Public Utilities Commission, rather than the Federal Communications Commission. Insufficient precedence exists to encourage widespread provision of such services. However CATV operators generally do not wish to be regulated by a state authority, as they fear this could lead to regulation of their entertainment video services.

Directly affecting the choice of microwave radio is the extent of frequency allocation available in the service area. Digital microwave radio makes an attractive local network medium, but only if adequate bandwidth is available. If a local network already exists in the area, charges for such service may be reasonable. Nine carriers have already filed for access to the DTS band (10.55 - 10.68 GHz) even before the equipment to provide such service has become commercially available.

A major factor which will affect selection among the ground networking options, in practice, is the path that the Bell System will ultimately take in the wideband local loop market. Today the provision of wideband local loops from the Bell System is limited by:

1. Availability. Only 95 cities have been designated for Dataphone Digital Services (DDS).

2. Lead Times. Six months to two years installation times are not uncommon.

3. Quality Considerations. Bit error rate specifications are not always met in practice.

4. Cost. At present, 56 kbps local loops are tariffed so high as to be uneconomical in most cases.

In spite of the highly touted advancing "Digital World" to date, the primary digital conversions have been made only on interoffice links. At present, there are tariffs for wideband local loops in many cities, but only about 425 such loops are being provided by the Bell System, nationwide. Until the Bell System begins wholesale conversions of all local loops from analog to digital, private wideband loops may be expected to dominate the marketplace.

System Requirements

This subsection presents the major requirements which influence the selection of a regional distribution system architecture. These may be categorized as technical performance requirements and operational requirements. Each category of requirements is discussed below.

In order to realize an effective concentration of data as a means for increasing transmission efficiency, it is necessary to be able to characterize the "burstiness" of the data flowing in each direction over each link. This concentration, however, carries with it a statistically predictable degree of blockage. By blockage, we mean that either no path exists through the network momentarily, or that data are delayed excessively in transiting the network. For both voice and data services, blockages in excess of one percent will be assumed unacceptable. The establishment of video services may be scheduled. For this reason, call set-up delay is the applicable parameter for these services.

The terrestrial link parameter requirements postulated for this investigation should be considered as typical, rather than definitive, of the traffic and service requirements for ground concentration networks. While limited parameter variations from these nominal values are expected, it would be a purely academic exercise to attempt to select a system architecture for a completely generalized set of link parameters. For this reason, no such attempt has been made.

Availability requirements define the probability that a path will meet the specified technical performance requirements at any given instant of time. In general, availability depends on the Mean Time Between Failures (MTBF) and the Mean Time To Repair (MTTR) these failures, as well as the degree of redundancy incorporated within it (if any).

Any data communications path in a regional/local distribution network may generally become unavailable due to equipment failure anywhere within the path. The subscriber's terminals are not included in these considerations, as they are not part of the network proper. Failures include prime power failure (except at customer sites); transmission link failure, for example, caused by precipitation attenuation in excess of the transmission link margin provided in the system's design; traffic overload, which causes blocking and results in circuit set-uptime or throughput delay in excess of permissible amounts; degradation of the quality of the transmission path, resulting in a bit error rate in excess of the specified value; and short interruptions occurring as a result of switching from operating to standby equipment, and/or power line "hits."

The sources of outage that are specifically excluded from availability considerations include prime power failures at customer locations, human error which may disable operation of part or all of the network, and earthquakes, hurricanes, tornadoes, and other unpredictable meteorological phenomena.

The specification of availability includes percent of time a piece of equipment, subsystem, or link is available, maximum permissible continuous outage period; for example, 100 msec for equipment switchover and 24 hours for repair of failed links, maximum permissible undetected Bit Error Rate (BER) when forward acting error control techniques are employed, and time interval over which BERs are to be determined. It is appropriate to note here that this measurement is statistical in nature, and is a function of both the transmission link and the data source characteristics.

The maximum system specification for availability is taken as 0.9995 over an average year. This allows up to 4.4 hours of outage per year to be experienced by each subscriber. The distribution of outage times, however, drastically affects the subscribers' perception of his "grade of service." For example, if only one or two outages, each of several hours' duration are

experienced per year, this is usually preferable to 1000 outages per year, each of 0.25 seconds' duration, even though in both cases the availability is 0.9995.

This concept may be expressed with the aid of the parameters, UI, the number of unscheduled service outages per year, and DI, the duration of unscheduled service outages.

Both of these are statistical quantities, which are most easily described by their mean or expected values. For the sake of example, it would be desirable if the mean value of DI were at least 22 minutes. Correspondingly, the mean number of unscheduled service outages per year, UI, should be below 12. This combination implies about one service outage every month, and is probably comparable to the rate of service interruption for most terminal equipment.

System availability may be expressed as:

$$A = \frac{MTBF}{MTBF + MTTR}$$

where MTBF and MTTR are for the entire regional/local network. The availability of network which can be decomposed into a series of links or components is equal to the product of the individual availabilities, provided that the failures occur independently. In that case, if the MTBR and MTTR of the component parts are known, then, the system availability may be expressed as:

$$A = \prod_{i=1}^{N} A_i$$

where the A_i are the individual component or subsystem availabilities for a system of N components or subsystems in series (tandem).

Availability may be calculated for redundant network configurations as follows. If A_1 and A_2 represent the individual (independent) availabilities associated with two parallel branches of a network, only one of which is required to be operating, then the redundant configuration is said to

have failed when both independent branches have failed. From this, the availability of the redundant configuration is:

$$A_R = 1 - (1 - A_1)(1 - A_2)$$

Generally, we have $A_1 = A_2$, yielding

$$A_R = 2A_1 - A_1^2$$

This equation for double redundancy can easily be extended to situations with redundancies of higher order.

In general, the values of MTBF and MTTR will depend on the particular media selected to comprise the regional/local network. However, for a network of this type, the MTTR is expected to be dominated by the repair technician's travel time. Modular equipment combined with automatic fault detection drive repair time into the range of several minutes, once the technician is on site. Unless otherwise specified, an MTTR of three hours will be assumed.

The nominal bit error rate requirements for each end-to-end path in the regional/local network will be taken as 10^{-6}. That is, the connection between each subscriber site and the CPS earth station should support a bit error rate of 10^{-6}. In general, each of these connections consists of more than one link. We will assume that the sources of error for the various links are uncorrelated, i.e., that the bit errors are purely random in nature. In this case, the bit error rates on the individual links simply add together, and their sum is reflected as the end-to-end bit error rate.

Thus, if we assume that no more than five links are typically required to constitute an end-to-end connection from a subscriber site to an CPS earth station, the overall bit error rate requirement can always be satisfied provided the link BER is below 2×10^{-7} for each link.

The measurement interval for BER may be estimated with the aid of the following table:

Date Rate	Mean Time Between Errors at BER = 10^{-6}
56 kbps	17.9 sec
224 kbps	4.5 sec
1.544 Mbps	0.65 sec

For a statistically significant result, the measurement interval which is selected should be large compared with the mean time between the occurrence of bit errors. A measurement interval of 3 minutes should suffice at 56 kbps, while only about 7 seconds are required at a data rate of 1.544 Mbps.

Another approach to the measurement of bit error rate employs the concepts of "error free seconds," i.e., the percentage of one-second intervals which are error free. The correspondence between bit error rate and error free seconds depends on the distribution of bit errors.

This in turn depends on the medium employed for transmission. For example, the errors observed on a microwave link usually follow a Poisson distribution, while those observed on a cable link are more "bursty" in nature.

The following example will serve to show how error free seconds may be converted to bit error rate. Suppose a link is specified to have 99.95% error free seconds at a data rate of 56 kbps. Thus, only five in 10,000 (or one in 2000) one-second intervals may be expected to contain bit errors. At 56 kbps, a total of $2000 \times 56{,}000 = 112 \times 10^6$ bits may thus be expected to elapse between errors, for an equivalent bit error rate of $1/(112 \times 10^6)$, or 8.9×10^{-9}.

Figure 3.1-3 shows the suggested BER as a function of information rate for various services which could be provided by a 30/20 GHz station. The diagram clearly shows that many of the indicated services can be easily supported without the need for special treatment. Other services would be quite degraded if offered "as is" to the network. Of these, there are two categories, each requiring a different approach to lower the experienced error rate. One class consists of very short messages that need to be quite accurate. These include computer time sharing, supervised alarm monitoring, access control, and electronic funds transfer.

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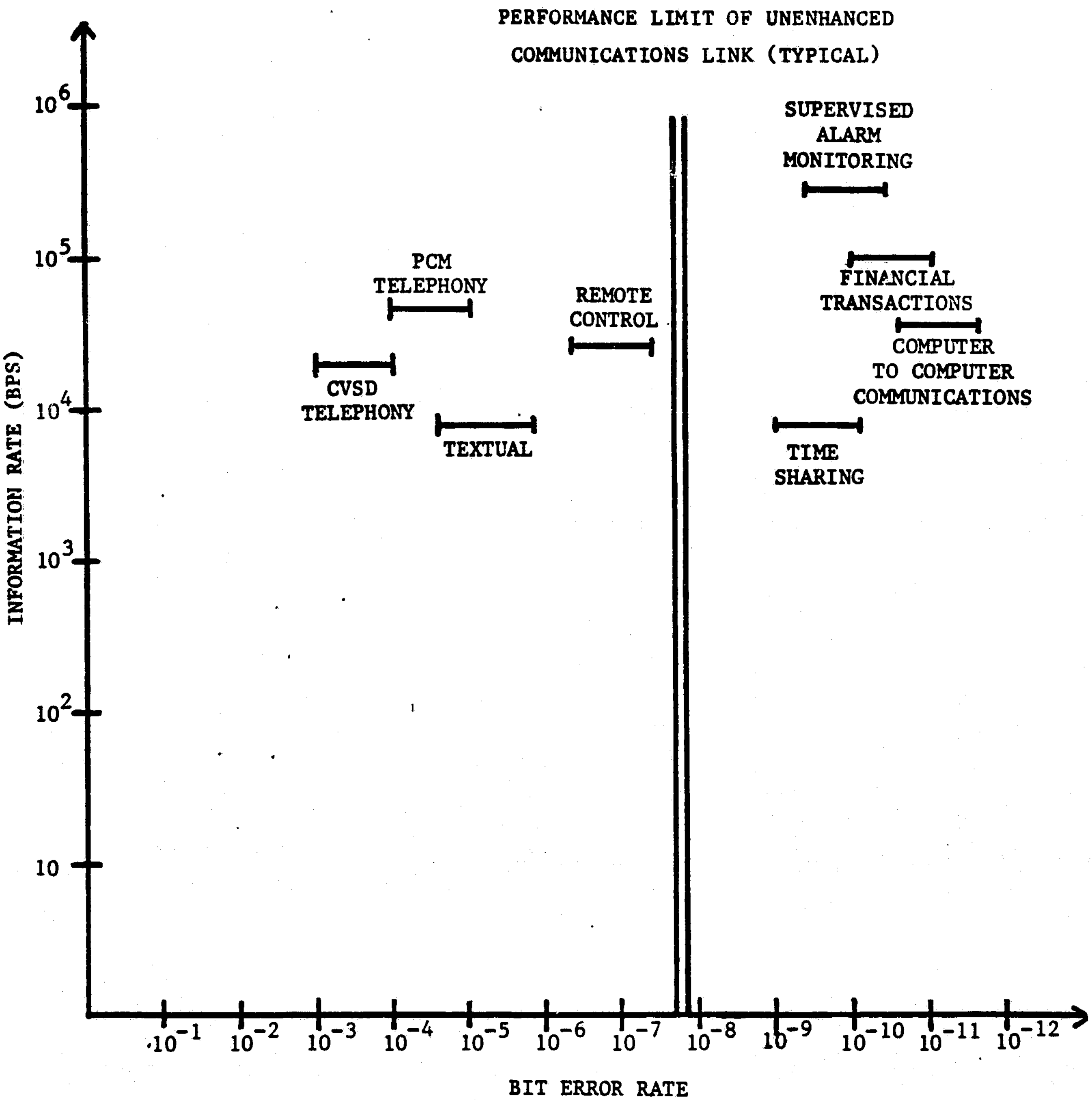

Figure 3.1-3. Bit Error Rate Vs. Information Rate for Various Categories of Digital Services

The bit error rate for these services can be reduced by using a positive acknowledgement system. This protocol requires the recipient of a transmission to send it back to the originator. Should the originator not receive an identical copy of the original message, he transmits again. This scheme will be necessary for electronic funds transfer, access control and upstream traffic from interactive terminals. In the case of security monitoring, when an alarm is received, the location reporting an alarm is repolled several times and a majority voting protocol is invoked at the head end to determine the validity of the alarm.

The second class of service which would benefit by having a BER better than that supported on the communications plant is computer-to-computer communications. For these high volume transmissions, a positive acknowledgement protocol would be grossly inefficient. One option is to employ Forward Error Correcting coders and decoders. These devices add additional redundant information to the user data in order to protect it from noise. This has the result of reducing the effective transmitted information rate and is not usually done when bandwidth is at a premium. Standard data transmission formats (e.g., SDLC, HDLC) surround small amounts of data with error detection bits, and accomplish error-free transmission by means of retransmission of only a small portion of the data.

Delay requirements are generally specified in a communications network and include set-up and tear-down delay, and throughput delay

Call set-up delay is the time required to establish a path through the network. This is an especially critical parameter in a switched network, but is generally of importance in any network whose resources are shared among its users. Similarly, call tear-down delay is the time required to release a path which has been established through a network.

In most networks, the call set-up and tear down delays are not fixed. That is, a range of delay values is possible for each. Thus the most useful way of treating these delays is through the use of probability models. Typically, a distribution function may be found for each delay of interest. The allowable delay value is then specified as a percentile, usually 95% or 99%, meaning that the specified value may be expected to be met in at least 95% or 99% of all instances.

Call throughput delay is best described statistically as well. This delay is the observed end-to-end transit time of a signal through the network, once a path (call) has been established. In general, it consists of the components, processing time, TDMA frame latency, if any, access collisions/backoff times and signal propagation time.

In the network under consideration, any Forward-Acting Error Control (FEC) and/or Automatic Repeat Request (ARQ) delays are not included in the specification of throughput delay.

3.1.2 CONCEPTUAL ALTERNATIVE GROUND NETWORKING ARCHITECTURES

Transmission Technologies

In general, transmission technologies may be classified as either guided or unguided. The Digital Termination System (DTS) is one example of unguided transmission, which generally includes any form of atmospherically radiated energy. Other examples of unguided transmission technologies include point-to-point digital microwave radio, and atmospheric optical systems.

Guided transmission media, on the other hand, are those which are confined to narrow physical paths. Energy must be inserted or extracted from these paths by means of a physical tap in order to perform basic communications functions. This distinguishes a guided from an unguided medium, in which energy is received "over the air." Another important difference between these two categories is that the medium is an important cost element only in guided systems. Examples of guided media include wire pairs (e.g., DDS), coaxial cable with modems, and optical fiber with access electronics.

At frequencies above about 100 MHz, electromagnetic energy which is radiated through the atmosphere generally travels in straight lines over short distances. This implies a requirement for an unobstructed line of sight path for any of the unguided transmission technologies. Since we are concerned with transmission within a city area, the question naturally arises as to the likelihood of obtaining such an unobstructed line of sight between a well chosen central distribution point and various subscriber sites, whose locations are not known a priori.

The probability of a clear line of sight decreases with increasing distance from the node. The rate of such decrease, however, is generally of an exponential form. This indicates that, in urban situations, the achievable range of a particular transmission technology may tend to be of only slight practical importance past one or two miles.

The real consequences of limited line of sight paths deal with basic economic viability. If a particular path is obstructed, it is considered likely that some intermediate point can be found at which to install a repeater to circumvent the obstruction. For most systems, the economic consequence of this, however, is to approximately double the installed cost per subscriber. Thus, the percentage of subscribers who require such special treatment may dominate the overall cost of service.

Another real-world line of sight limitation arises due to the construction of new buildings which might block an existing path. As this is an item beyond the control of the carrier, it cannot be properly planned for. When it occurs, however, typical reactions might include relocating an affected concentration node, adding a repeater to circumvent the new obstruction and repointing a subscriber link to "home" on a different concentration node, if one is available.

Any such reaction tends to increase the cost of service.

Concentration and Routing

There are several types of routing equipment, including switching Statistical Multiplexers (Stat Muxes), circuit switches, data PBXs, and packet switches.

There is reason to believe that most large data users will have a data PBX or the equivalent. This is due to the fact that internal communications play a large factor in the day-to-day operation of a business organization. With the advent of executive work stations (CRT, keyboard, keypad and telephone), many firms may wish to combine the management of voice and data communications through the introduction of a digital PBX.

The several forms in which data PBX's output are found include Port Level Data and Voice, Port Level Data and T1 Voice, and T1 Voice and Data.

Port Level Data and Voice are best suited to the concentration type ground network. Outputs to the network are at the port level and only active ports are granted access to the network. Ports may also be multiplexed together and the aggregate passed via point-to-point links.

Port Level Data and T1 Voice would require a mixed treatment in that T1s are a continuous data stream, full period, independent of actual usage. On the other hand, the port level data can be further concentrated, due to fluctuations in usage. In this case, point-to-point links are attractive, but link control may be a problem if the port level multiplexed output varies in rate due to demand fluctuations. Varying the rate has no advantages.

T1 Data and Voice may be the preferred application as telecommunications users integrate their traffic. In this case, the T1 outputs will be sent via point-to-point links to the central node, then over the satellite to the user destination. This is most attractive when a subscriber has a great deal of voice traffic. However, the data must be compatible with the T1 format. This is accomplished through bit stuffing or oversampling. The chosen technique will have an impact upon routing only if data bound for separate locations is multiplexed together and placed in one 8 bit slot of the DS-1 frame.

Oversampling is a simple and neat way to fit data speeds of less than 19.2 kbps into the DS-1 frame format, which consists of 24 64 kbps streams. However, it is wasteful of bandwidth. This can be a crucial problem when bandwidth is at a premium, e.g., when rights of way must also be rented. Naturally, such bandwidth inefficient techniques are unacceptable for satellite traffic.

Telephone Cable Pairs

The most pervasive transmission medium by far is telephone-type cable pairs. Together, AT&T and the independent telephone companies own 99.95% of the wire loop plant in the United States. Thus digital services provided over these pairs provide an ideal baseline for comparison with other media. Because cable plant represents so huge an investment in labor and materials, it is not likely to be removed or replaced. Instead, we may expect it to continue growing and to be enhanced electronically to meet new service requirements.

Wire pairs connect subscriber stations to the switching network at the main distribution frame in a telephone wire center (end office, CDO, 4C office, etc.). Four gauges are now in common use--19, 22, 24 and 26. The use of the coarsest of these, 19 gauge, in new installations is becoming rare. The use of 26 gauge in UNIGAGE construction is comparatively recent but will become widespread, mainly outside metropolitan areas. In downtown high density areas the use of dual expanded plastic insulated cable (DEPIC) with 25 gauge copper conductors (Bell System's Metropolitan Area Trunk (MAT) cable) is being introduced. Besides saving material, MAT cable also allows 30% more pairs to be installed in an underground duct than would 22 gauge cable. Widespread use of MAT cable in future loop construction is expected.

Ordinary telephone loop pairs are able to transmit frequencies tens or hundreds of times greater than those used for voice transmission. Telephone companies are only beginning to use them to transmit these broader bandwidths. Because attenuation in a cable pair increases continuously but relatively slowly with increasing frequency, it is not easy to define a "bandwidth" beyond which the cable is no longer usable. Degradations due to electrical noise and due to crosstalk (the coupling of energy between pairs in the cable) tend to place limitations on transmission at higher frequencies, however. Transmission characteristics of telephone cable have been extensively documented. For example, see Eager, Jachimowicz, Kolodny and Robinson, "Transmission Properties of Polyethylene Insulated Telephone Cables at Voice and Carrier Frequencies," Communications and Electronics, Nov. 1959 and Jachimowicz, Olszewski and Kolodny, "Transmission Properties of Filled Thermoplastic Insulated and Jacketed Telephone Cables at Voice and Carrier Frequencies," Proc ICC '72.

Cable Pair gain techniques are commonly employed to increase the number of voice channels per cable pair. Two examples illustrating the type of digital transmission used in the telephone loop plant for this purpose are the SLC-40 and the SLM digital subscriber carrier systems. In SLC-40 up to 40 voice channels are provided via a remote terminal, which can be as far as 50 miles from the telephone central office. Each voice channel is available as a wire pair at the subscriber's premises, served by the remote terminal. Call switching is performed at the central office; transmission between central office (CO) and the remote terminal is by means of T-1 carrier repeated lines. Pair gain is 36. In SLM (Subscriber Loop Multiplex) systems, more

sophisticated techniques are used. An SLM system consists of up to 6 remote terminals, connected to the CO over T-1 repeated lines, as well as pairs for fault location and order wire, the maximum distance being 50 miles. The remote terminals need not be in one location. Switching is provided in a central terminal at the CO. Pair gain is 74.

Although subscribers whose locations are served by digital carrier systems typically see voice bandwidth wire pairs, it is also possible for a subscriber to access a digital T-1 port device in certain locations.

Table 3.1-1 presents a figure of merit for full size paired cable. It expresses the unrepeated channel-mile capacity based on T-1 technology. It also summarizes the improvement presently projected based on more sophisticated equalization and transmission techniques.

Paired Cable Architectures: Three approaches to the architecture of paired cables are seen in varying degrees in modern telephone loop plants. Economic considerations dictated their introduction. Cities and other demographic units traditionally developed in patterns that did not take telephone distribution into account. Generally growth takes place over a long period of time and in quite random patterns. The classical problem of the telephone outside plant engineer has been to wire customers to their serving central office in a way that best balances transmission performance against investment and maintenance costs.

Table 3.1-1. T-1 Channel Miles/Cable

Cable Type	Present	Future
Alpeth-Stalpeth 22 Gauge (also comes in 19, 24, 26)	3.9×10^4	7.8×10^4
PIC-22	3.9×10^4	7.9×10^4
LOCAP-22	2.8×10^4	5.5×10^4
MAT-DEPIC-25	5.2×10^4	10.4×10^4

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A traditional approach to economic engineering of subscriber loop plant has been to attempt to minimize the amount of copper that is used. In the most common version of this approach, called "resistance design," the finest gauge of wire is used for subscribers nearest the central office. As distances increase, losses increase and coarser gauge wires are used to keep overall performance approximately the same for all loops. The range of gauge sizes found in a typical application is shown in Figure 3.1-4.

It is also necessary to choose the proper number of pairs in a cable for various sections of a loop network. If large reserve pair-capacity exists, rearrangement costs to cope with moves and growth will be rather low, but capital costs resulting from unused pairs will be relatively high. If, on the other hand, new cables are not put in until existing cables are nearly full, capital costs will be low, but rearrangement costs for providing cable pairs where and when they are needed will be extremely high. It has been customary to attempt to balance these conflicting effects by putting in new cables when between 80 and 85 percent of the pairs in existing cables become full.

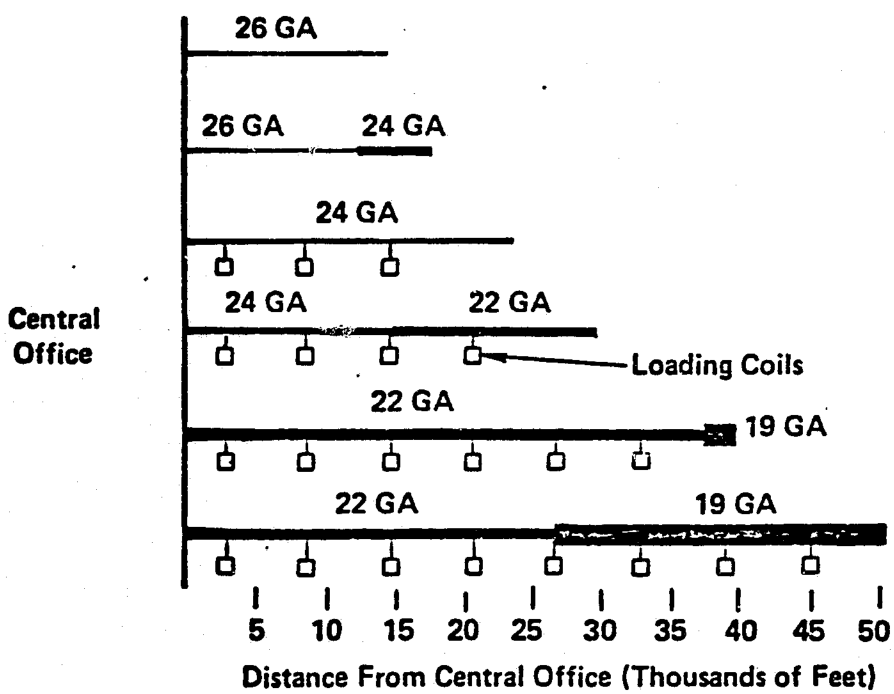

Figure 3.1-4. Resistance Design

For many years geographical or topological assignment of cables and pairs was based upon the idea of multiple outside plant. With this philosophy, cable pairs are distributed quite universally throughout a geographical area. When a transmission path from a subscriber location to a central office was required, arrangements were made at distribution points to connect available pairs in various cables together as needed, as shown in Figure 3.1-5. In order to keep the cost of this arrangement from being prohibitive, all pairs were generally not available at all cross-connect points. While doing this decreases costs it increases the chance that pairs will be available in a cable but would not be accessible where needed, and extensive rearrangement may be necessary when cable fill gets high. A more serious drawback to multiple outside plant design is the administration of unused portions of cable pairs. When a connection is made to a cable, any unused portions remaining connected can result in extreme degradation of transmission performance. These unused cable pair sections are called bridged taps and are

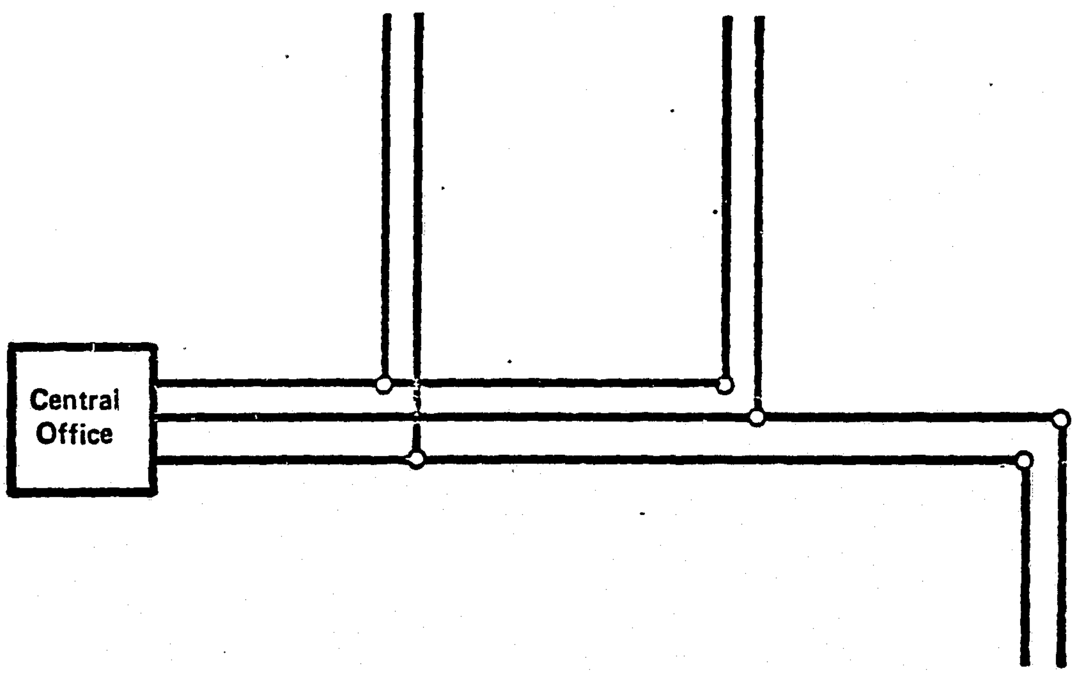

Figure 3.1-5. Multiple Outside Plant

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analogous to tuned organ pipes that can resonate at a frequency related to their length. The type of degradation that results from these electrically resonant sections is not particularly objectionable with speech, but has been found to be devastating for digital transmission.

In order to minimize the problem of bridged taps, an approach called dedicated outside plant was developed. With this approach, which is now widely found in plant, one or more permanent connections are provided between the central office and subscriber locations, as shown in Figure 3.1-6. This arrangement simplifies construction and assignment.

A permanent interconnection of pairs in the final distribution plant and feederplant takes place in two stages - as pairs are successively connected together in control points and access points. Feeder pairs are spliced into a control point and distributed to access points using distribution cables. When a customer requires a connection, a distribution pair available in a

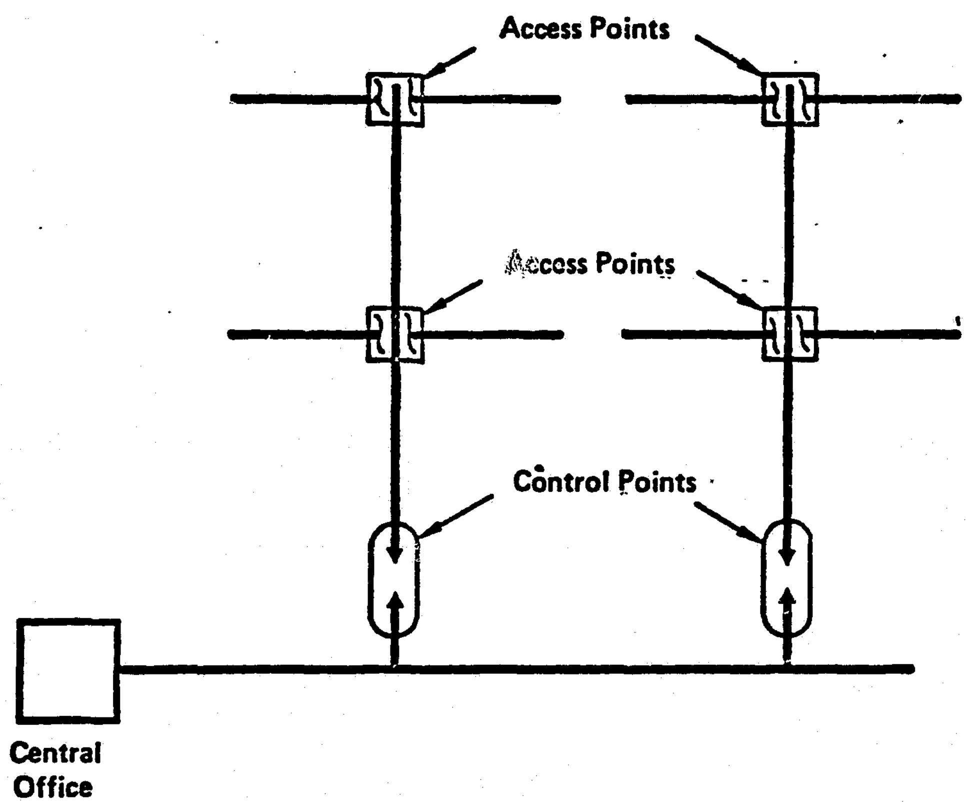

Figure 3.1-6. Dedicated Outside Plant

terminal near his location is connected at the access point to one of the pairs already connected through the control point. Permanent connections to subscriber locations are thus created, eliminating network changes in response to in-and-out movement of customers.

The most modern approach in the topological design of outside loop plant, intended to overcome the difficulties of multiple outside plant and dedicated plant, is called Serving Area Interface Design or Serving Area Value Engineering. Although this concept was developed to meet the needs of plants consisting entirely of wire pairs, it is also a very convenient framework for the initial large-scale introduction of electronics into outside plant. The Serving Area Interface also provides a convenient location for the introduction of pair gain systems as well as the digital transmission systems that we have been discussing. It provides convenient points for electronic system terminals, at which short digital links to the subscriber sites may terminate.

The Serving Area Interface Design concept, illustrated in Figure 3.1-7, provides a permanent subscriber connection in the central office, and at the same time, maintains flexibility between feeder and distribution facilities. Under this concept feeder routes are divided into discrete areas called serving areas, each of which has an interface for terminating distribution and feeder cables. Serving areas are laid out to contain perhaps 500 ultimate equivalent telephones. The serving area interface provides a point of flexibility and a means for orderly interconnection of the (ultimate size) distribution facilities to the feeder plant (which has a shorter relief interval).

A possible future architecture for digital loop transmission is based on rings. One proposal advanced by Bell Labs is illustrated in Figure 3.1-8. Each loop is a digital data transmission channel. Three sorts of boxes appear in the rings:

1. Each ring has a box A which contains a clock and a buffer, so as to time and close the ring. A also performs other functions.

2. Unless a ring is a trunk ring, it also has boxes B which put blocks of data on and take blocks of data from the ring.

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3. Rings are interconnected by boxes C, which transfer blocks of data from one ring to another and perform other functions.

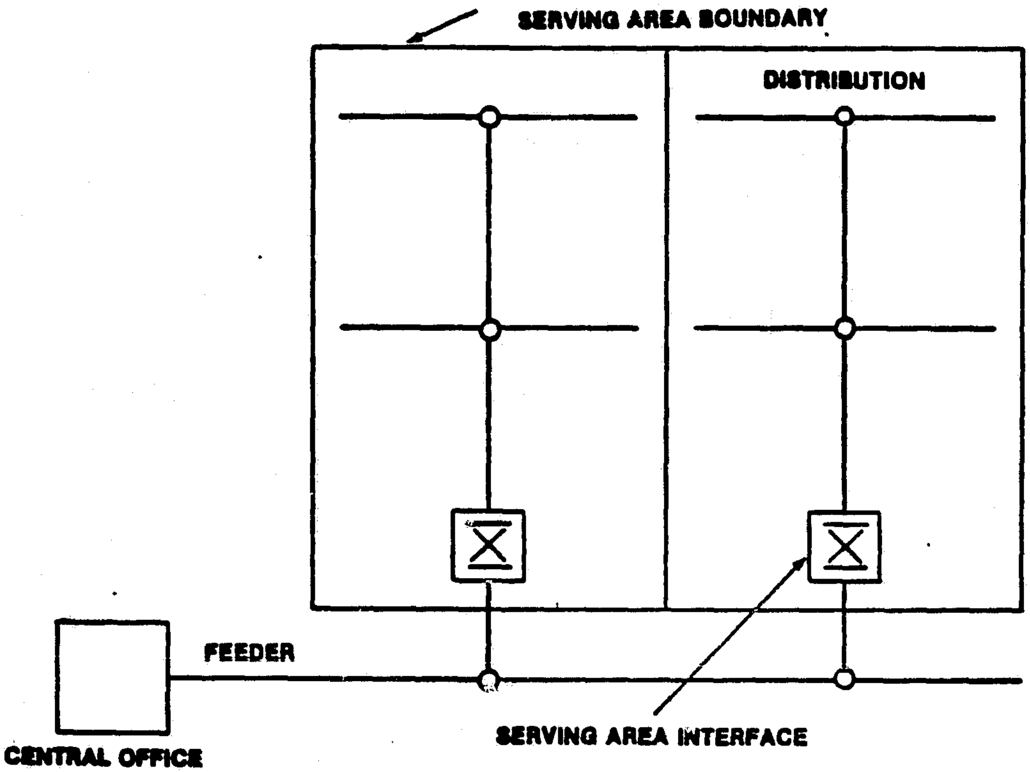

Figure 3.1-7. Serving Area Interface Design

Rings need not be synchronous, and speeds of transmission on different loops can be very different. Thus, transmission means can be fitted to the traffic. In transferring blocks from one ring to another, buffering will be provided to take care of differences in bit rate. Commonly, the buffer size will be one or more block lengths. This buffering function may introduce delays into the transmission of digital data.

Other Channel Services Provided by Telephone Companies Modems

Because most of the telephone loop plant is still highly analog in nature, interface devices are required to adapt digital subscriber data to the analog telephone plant at the point of entry - the subscriber wire pair. These interface devices, or modems, may be obtained either from the local telephone operating company or from outside suppliers.

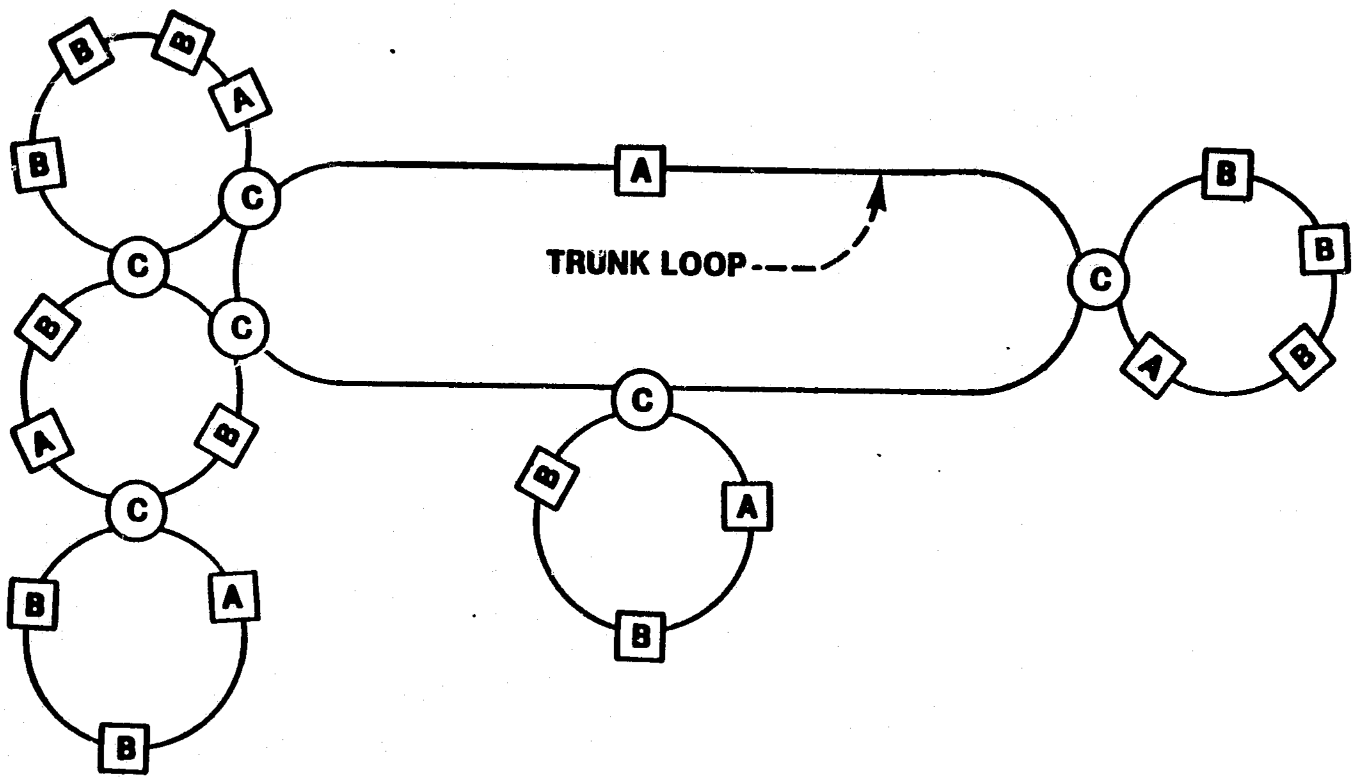

Figure 3.1-8. Digital Transmission System Based on Ring Architecture

Table 3.1-2 lists typical modems available through AT&T. Some of these are sophisticated, containing adaptive equalizers which compensate for transmission line distortions automatically, thus facilitating transmission at higher data rates. Some require a private conditioned line, which is a pair of conductors in the cable to the CO which bypasses the switch, is wired to appropriate repeaters, and leaves the CO in another cable. Equalization is provided by the telephone company (included in the leasing charge) which conditions the line to the proper attenuation and phase characteristics as functions of frequency.

Dataphone Digital Service (DDS), which is AT&T's basic digital data communications service, is scheduled for rapid introduction into 100 metropolitan areas. Digital transmission service--without the need for costly modem interfaces--is provided over private line facilities using two half-duplex wire loops (non-loaded) from the serving office. DDS provides both point-to-point and multipoint links operating at rates of 2400 bps, 4800 bps, 9600 bps, and 56 kbps.

DDS subscriber equipment consists of the data terminal and a unit for retiming and generating bipolar signals. AT&T supplies the Data Service Unit or Channel Service Unit.

Table 3.1-2. Modems Provided By AT&T

208A	4800 bps Private Line
208B	Similar to 208A but for use on DDD network
201C	2400 bps DDD or unconditioned Private Line
202S	Asynchronous 1200 bps DDD
202T	Asynchronous up to 1800 bps Private Line
209A	9600 bps Private Line
407A	Receives and decodes Touch Tone Signals for Digital Inquiry Voice Answerback (DIVA)

The telephone company has developed a family of TDM multiplexers to interface digital local loops onto 64 kbps channels. For example, 20 loops, each carrying 2400 bps, or 10 loops at 4800 bps, or 5 loops at 9600 bps are multiplexed together. A second level of multiplexing is then used to combine various 64 kbps data streams. Two TDM multiplexers are in widespread use for this purpose. The first--designated T1DM--combines 23 synchronous 64 kbps data channels feeding in from various subscriber locations in a metropolitan area. The output feeds a repeated T-1 line. The second--designated T1WB4--combines up to 12 channels of 64 kbps data streams with 12 channels of T-1 encoded voice, each of which is also at 64 kbps. The output feeds a repeated T-1 line. The T1WB4 is employed where there are digital voice lines and too few 64 kbps data channels to require the T1DM. Having the capability to mix data and voice on the T-1 repeated line adds versatility to the digital transmission system, and provides capabilities which presumably could be used in the wire loop plant eventually.

Within the DDS network data signals are transmitted on T-1 repeated lines and must frequently be sent over distances in excess of 200 miles, necessitating the use of microwave links. These data signals "hitchhike" on existing microwave channels using the channel space available below the spectrum occupied by voice channels, the technique being named Data Under Voice (DUV). The Bell system's 1ARDT digital radio microwave terminals make use of this technique.

With more and more digital transmission equipment being installed by the telephone company each month, it is obvious there is a trend toward an all-digital interoffice trunking system. Each new digital system introduced, however, has had to pay its way by offering cost savings over other means of handling the transmission of voice circuits. Once a system has been proven, it tends to become entrenched.

Figure 3.1-9 shows the anatomy of a digital network, illustrating the hierarchy of data rates (bit rates) and the multiplex structure for changing from one data rate to another. In the transmission facility column is a list of the types used at each bit rate. T-1 was introduced in 1962 and today has millions of channel miles installed. Because the technology is so well understood, the basic building blocks of T-1 have proliferated and infiltrated into the wire loop plant, mostly in the form of pair-gain systems.

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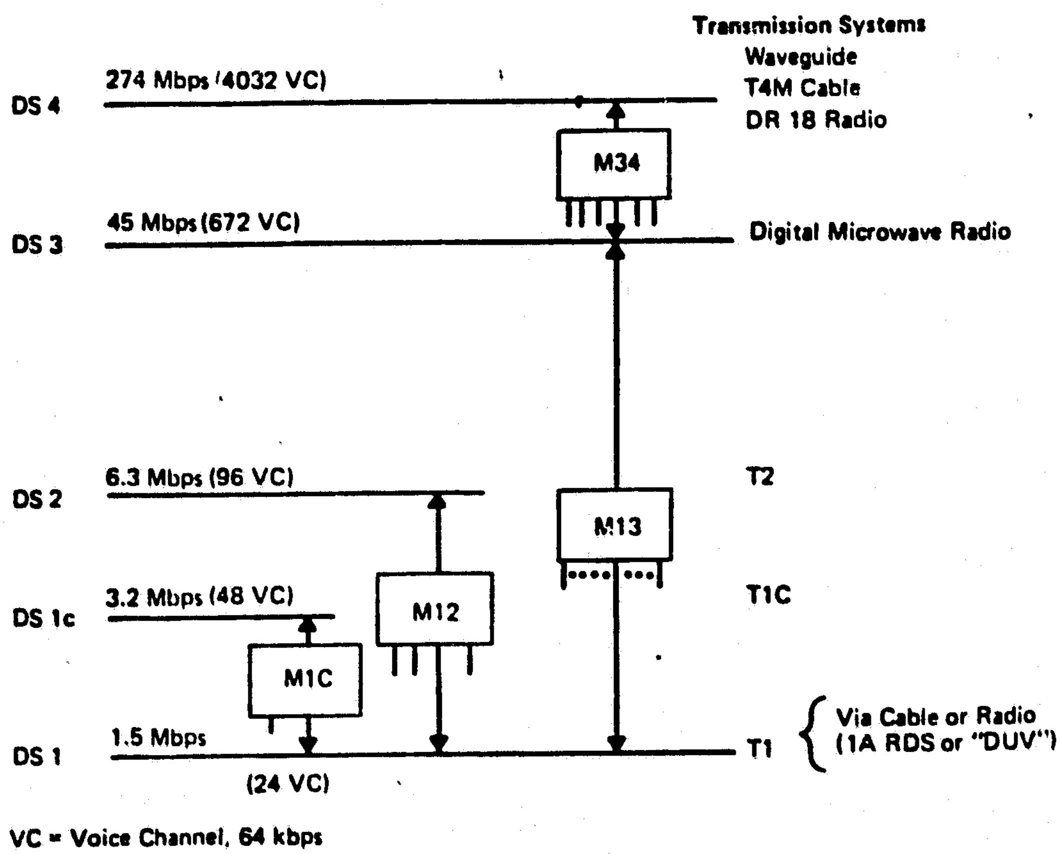

Figure 3.1-9. Bell System Digital Multiplex Hierarchy

Conditioned Lines: Over the years a family of conditioned lines has come to be offered in telephone company tariffs. They generally apply to the basic 3002 channel, which is a voice bandwidth private line. Recently a new grade of conditioning (D-1) has become available (for two point 3002 channels only). Unlike the C1 through C5 conditioning, the bandwidth parameters are not affected by D-1 conditioning, and D-1 conditioning is not achieved by placing equalizers in the line as is done for the C types of conditioning. Rather, the facilities used to provide the service are chosen to minimize noise and to minimize the harmonic distortion. D-1 conditioning is necessary to support 9.6 kbps operation with the 209A data set.

General Point-To-Point Unguided Media Architectures

There is a general class of media which may be categorized as unguided which include microwave radio transmission systems and atmospheric optical (IR) transmission systems.

From the standpoint of architecture design, all unguided media are, to first order, equivalent. The differences between the various media lie principally in such factors as achievable range/data rate/availability/bit error rates, regulatory factors, costs and setup times.

Atmospheric optical systems generally exhibit ranges of one mile or less at data rates and availabilities which would be of interest to the 30/20 GHz program. As their costs are generally comparable to the cost for a microwave link, their advantage lies chiefly in the regulatory area. The Federal Communications Commission at present has no jurisdiction over optical communications media. This means that prior frequency coordination is not required, and that long licensing delays may be avoided. On the other hand, no protection against interference is possible without regulation, so that long-term service is difficult to guarantee.

In most respects, optical links function and are employed in ways that resemble those for microwave systems. In fact, applications for optical links can be thought of as a subset of those available to microwave systems in general. The bandwidth, range, and operational reliability of optical links are more restricted than those of microwave systems.

Wire and cable installations are at a severe disadvantage if new lines must be installed over terrain with severe obstacles (bodies of water, roadways, dense urban environment, etc.). These considerations alone may dictate the choice of either a microwave link, or an optical communication link, both techniques being effective substitutes for cable. Time considerations also work in favor of microwave and optical links, in that they can be made operational in a shorter time. However, if a cable of appropriate characteristics is already available between the two points to be connected, it will almost always be preferred.

An FCC license is required for any microwave installation, and a variety of FCC, PUC, and local ordinances usually regulate the installation of a new wire or cable system. As matters now stand, optical links do not need government license; this represents a substantial advantage for communication links that must be implemented quickly.

There is a possibility that safety licensing will have to become a part of an optical communication system, particularly if lasers are employed. However, this probably will take the form of type certification rather than licensing of specific installation sites.

Except in the most extraordinary outdoor climates, optical communication links cannot be viewed as completely reliable for any but the shortest distances, because of the combined atmospheric effects of turbulence, absorption, and scattering. Many applications do not require absolute reliability, but the natural tendency of the user is to avoid the compromise of unscheduled communication outages unless an optical link provides other significant advantages.

There are places (e.g., deserts) where weather never presents a problem and there are locations where the path is totally enclosed. The use of microwave communications links inside buildings can be unsatisfactory because of multiple-path interference and the shielding and resonant effect of structures and objects within the building. In a heavy industrial environment there often is a severe electromagnetic interference problem. Switching of heavy machinery and poorly regulated power supplies lead to severe noise

interference in both cable and microwave systems. If the transmitters and receivers themselves can be adequately shielded, optical communication links can provide immunity to noise.

With today's technology three system possibilities are externally modulated CW lasers (HeNe), modulated light-emitting diodes (LEDs), and modulated laser injection diodes (LIDs).

Under poor weather conditions the signal loss due to atmospheric attenuation does not change significantly over the wavelengths encompassed by the competing techniques. Thus, the ultimate range in which usable signals can be detected really depends on the effective brightness of the several sources. The effective power must be evaluated in terms of the modulation and detection methods (peak brightness or average brightness); in the case of solid-state devices, because of thermal effects the peak brightness is also a function of the duty cycle.

An externally modulated helium-neon laser can have an output effective brightness on the order of 10^4 watts/cm^2 sterad. The average brightness of an LID is of the same order, and peak brightness can be about 10^7 watts/cm^2 sterad. On the other hand, typical LEDs have an average brightness of about 1 to 10 watts/cm^2 sterad.

All other things being equal, the relative brightness values show that the helium-neon and solid-state laser systems should have about the same transmission range. In special applications of the LID that can take advantage of the high peak power, longer effective transmission ranges should ultimately be available. The LED is at a severe disadvantage in range.

The channel capacity and the signal quality are determined by the characteristics of the modulation achieved by the various devices. Light-emitting diodes are by far the most convenient to operate and have the greatest versatility; their output varies approximately linearly with the drive current, and they can be modulated at frequencies up to at least 50 MHz. LEDs can be used conveniently to transmit both video and high-speed data.

The LID is a different kind of device, in that it is binary. Depending on the level of sophistication and complexity of the design, the typical limited modulation frequency is somewhere between 300 kHz and 3 MHz. These limits occur because of the practical difficulties in generating and detecting pulses shorter than a few nanoseconds, coupled with the low (0.1% to 1%) duty cycles which are allowed.

Externally, modulated helium-neon lasers can be modulated at frequencies competitive with LEDs. Nonlinearities in the modulator and the associated drive circuitry have limited the quality of the signals transmitted. This is not a limitation for data transmission.

Apart from cost considerations, the three approaches to optical communication through the air present some significant performance differences. Without repeaters, LED systems offer the simplest data transmission at ranges up to a half or three-quarters of a mile. Beyond that range, the externally modulated helium-neon laser offers the only currently available data transmission alternative with ranges of at least two miles. Externally modulated lasers and LIDs are quite competitive for data transmission at ranges to about two miles.

It is difficult to make definitive cost comparisons among the competitive optical transmission systems, because they do not have exactly comparable performance characteristics, and installation costs can vary widely.

Commercial systems based on each approach have been offered. Prices quoted represent small quantity (experimental) production levels. It is unlikely that this field will develop so that these systems will become lower priced in the foreseeable future:

Manufacturer	Laser Communication Inc.	Op Com	Optran	Light Comm
Range (miles)	1 to 4	1-2	1/2-1	1
Data Rate (kb)	50	100	250	76.8
Light Source	He Ne	LID	LED	LED
Cost (one way)	$14,400	$9,600	$6,600	$12,000

It should be noted that these costs are not much smaller than those of microwave systems with ranges more than an order of magnitude greater.

In view of the foregoing, the most useful role that can be played by atmospheric optical systems is a short-term or interim service solution. Thus, while a more permanent solution is being implemented, optical systems can provide limited availability service over short distances.

Atmospheric optical systems are not in widespread use in the United States at this time.

Digital Microwave Radio

For applications in urban areas, clearances at the lower microwave frequencies are difficult to obtain, as large amounts of unused bandwidth must be available. The higher frequencies (above 10 GHz) which must be used, have the advantages that technology for efficiently exploiting these frequencies is now available or becoming available and relatively small diameter parabolic dish antennas produce narrow beams and high gains.

Signals in this frequency range are subject to deep fading (attenuation) during periods of heavy rainfall. Signals whose carrier frequencies lie between 60 and 120 GHz are subject to additional attenuation caused by molecular oxygen resonance effects. At still higher frequencies, water vapor causes large attenuation.

Above 10 GHz, rain attenuation rises rapidly with frequency, peaking at about 120 GHz, where specific attenuations of 30 db/km have been observed for rainfall rates of 100 mm/hr. Rainfall rates exceeding this value sometimes occur during thunderstorms, but these usually last only for brief durations and affect only small geographical areas at any instant.

Point-To-Point Digital Microware: Point-to-point microwave radio relay systems fall under the FCC's designation of a "fixed" service. The FCC has allocated the non-Government fixed service bands for use by common carriers, broadcasters, CATV systems, and various other categories generally classed as "private" radio users. In most cases, these frequency bands are shared among several of these user categories. This investigation considers only common carrier and "private" use bands. Existing digital microwave equipment has generally been accepted for use only in these bands.

In every case, these bands are shared with other services. These other services include various satellite services (e.g., fixed satellite, mobile satellite, earth exploration satellite services), the private radio services generally categorized as "operational-fixed," and mobile services. The three bands at 4, 6, and 11 GHz are the bands most used by common carriers for high-density intercity microwave relay.

In order to assign mobile radio licenses, the FCC has broken the private radio services into a number of classes and subclasses, as follows: Aviation Services (this class is not relevant to this study); Maritime Services (again, not relevant to this study); Public Safety Radio Services (Police, Fire, Local Government, Highway Maintenance,Forestry-Conservation, Special Emergency and State Guard Radio Services); Industrial Radio Services (Petroleum, Power, Forest Products, Motion Picture, Relay Press, Special Industry and Business Radio Services); Land Transportation Radio Services (Motor Carrier, Railroad, Taxicab and Automobile Emergency Radio Services); and Operational-Fixed Microwave Radio Service. Generally, anyone who is eligible for mobile and base station radio licenses under one of the first set of classes would be eligible for a microwave license under the Operational-Fixed class; in its Rules, the FCC has divided and subdivided the mobile radio classes but retained microwave as a single class. The eligibility requirements listed in the FCC Rules for each of the classes and subclasses is quite specific, with the exception of the Business Radio Service which is a kind of catch-all: the Business Radio Service is open to any person or institution engaged in commercial, educational, philanthropic or religious activities.

As is the case with the common carrier frequencies, each of these bands is shared with other services. Consequently, even though the FCC Rules may appear to allow the use of some of these bands, it may turn out that the sharing requirements make it impractical to operate fixed point-to-point microwave in some of these bands. It appears that the most important bands for the Operational-Fixed service are: 1850-1990, 2130-2150, 2180-2200 (these two bands are paired for duplex operation), 6525-6875, and 12200-12700. Of these, the FCC Rules prohibit Business Radio operation in the 1850-1990 and 6525-6875 MHz bands. The band 2150-2160 is shared with the Multipoint Distribution Service, and the band 2650-2680 is shared with the Instructional Television Fixed Service, and therefore neither is available for

point-to-point service. The band 13200-13250 is shared with the Television Auxiliary Service for video remote pickup use, and can be assigned to Operational-Fixed users only on a development basis.

The FCC issued a Notice of Inquiry in Docket 19311 in September, 1971, in order to gather information that could serve as a basis for authorizing digital modulation techniques in the microwave services. A large volume of technical comments were filed by virtually every company with an interest in digital microwave, including both manufacturers and users. After reviewing these comments, the Commission issued a Notice of Proposed Rulemaking in May, 1973, that proposed certain definitions; methods for calculating necessary bandwidths for various digital modulation methods; limits on out-of-band emissions; minimum voice circuit and data transmission capacity requirements; and frequency coordination requirements. Once again, a large number of parties filed comments, and the proposed rules were adopted with some modifications in September, 1974.

Docket 19311 was officially an inquiry into digital microwave for Common Carrier use, and resulted in rule change affecting only Common Carrier microwave bands. While it did not officially deal with Operational-Fixed microwave, many of the same rule changes have been incorporated or informally accepted as applicable policy for the Operational-Fixed services.

One of the major results of Docket 19311 was a recognition that analog microwave would continue to predominate below 15 GHz, and that it would have to be protected against adjacent-channel interference from digital microwave. This additional protection is necessary because in digital microwave, the energy is more evenly distributed across the allowed bandwidth than with analog microwave, and thus the energy density for digital microwave is greater near the band edge than for analog microwave. As a result, the emission mask for digital microwave below 15 GHz requires out-of-band suppression of at least 50 dB, while the comparable limit for analog microwave is 25 dB; for frequency bands above 15 GHz, a minimum of 11 dB suppression is required for digital microwave. The precise regulations appear in Section 21.106 (for common carrier microwave) and Section 94.71 (for operational-fixed microwave).

While the emission mask deals with out-of-band interference, digital microwave could cause co-channel interference by means of spikes or frequency tones resulting from repetitive bit sequences. Consequently, the FCC adopted a rule [Section 21.122(c)] requiring manufacturing to suppress such spikes, although it did not require manufacturers to use any specific method such as scramblers.

One issue in Docket 19311 was the efficient use of spectrum. This arose in two contexts: the data transmission rate and the voice circuit capacity. For microwave bands below 15 GHz, the FCC adopted both a minimum transmission requirement of one bit per second per hertz, and the following voice circuit requirements: */

Frequency Band (MHz)	Minimum Capacity (Voice Circuits)
2110 - 2130	96
2160 - 2180	96
3700 - 4200	1152
5925 - 6425	1152
10700 - 11700	1152

These minimum capacities were adopted for equipment designed to use the full allowed bandwidth; for equipment designed to use only half the allowed channel bandwidth (e.g., 20 MHz rather than 40 MHz at 11 GHz), the minimum capacity requirement would be halved.

These capacity requirements do not formally apply to Operational-Fixed bands, but the FCC staff has applied them informally. Moreover, because the Common Carrier and Operational-Fixed bands are often adjacent in frequency, most manufacturers have designed radios that are FCC Type Accepted for both services, and consequently meet the Common Carrier minimum capacity requirement in the Operational-Fixed bands.

*/ Frequency re-use by means of cross-polarization may be employed to meet these requirements.

The FCC maintains two kinds of data sources relevant to digital microwave radio: lists of radio licenses and equipment Type Acceptance data. Both data sources are generally available to the public, and the FCC's duplicating service will make copies, although several weeks' lead time is required.

The FCC Master Frequency List is a computerized listing of all FCC-issued radio licenses from 10 kHz up to 300 GHz. It includes experimental licenses as well as the regular services. It is available for examination and/or purchase in microfiche form, and for purchase as a set of computer tapes. The data base is reissued several times each year. In microfiche form, the data base runs nearly 105,000 pages.

The list is sorted by frequency, so that all licensees or any specific frequency are listed together. Consequently, it is not useful for trying to find a free channel within a geographical area. In addition, the frequency list is known to contain numerous errors. For example, a review of licensees above 24 GHz showed numerous listings for land mobile radio operations that should have appeared in the 30 - 50 MHz band rather than the 30-50 GHz band. Consequently, this data source must be used with care. It is likely that the similar data bases maintained by the frequency coordination contractors (e.g., SAFE and COMPUCON) are more correct.

It is not surprising that there are few licensees in the 18, 23, and 38 GHz bands. At 18 GHz, Bell Telephone Laboratories has several experimental licensees and New York Telephone Company has operating licenses for 274 Mbps radios; the NYTel licenses are for Greenburgh, Tarrytown, and White Plains, New York. Interactive Data Corporation has two licenses for the Farinon 18 GHz radios in Waltham, Massachusetts. Farinon itself has recently applied for licenses for its 18 GHz radios in San Carlos, California.

The only license of interest in the 23 GHz band is an experimental license issued to General Electric. At 38 GHz, the data shows that two OKI radios are licensed to Hayward Dodge of Hayward, California, and two are licensed to Art Iron, Inc. of Toledo, Ohio. In addition, four Norden radios were licensed to Datran, but those licenses apparently expired in 1976. In addition, Bell Telephone Laboratories has experimental licenses for the bands 38.6-40, 40-48, 50-51, 54.25-58.2, 59-64, 66-71, 76-86, 92-101, 102-130, 140-165, 170-182, 185-230, 250-300, and 300+ GHz. There are also experimental radio licenses in

the bands above 24 GHz issued to Westinghouse, McDonnel Douglas, Hughes Aircraft, CBS, Lockheed Aircraft, Martin Marietta, ITT Gilfillan, Goodyear Aerospace, and Raytheon. Most of these appear to be for the purpose of propagation tests.

The FCC requires that microwave radio transmitters be Type Accepted before they can be sold and used in the United States. The specific Type Acceptance requirements are specified in Sections 2.981-2.1005 of the FCC Rules. The application for Type Acceptance calls for a great deal of specific data about equipment, including complete circuit diagrams, instruction books, and measurements of power output, modulation characteristics, occupied bandwidth, frequency stability, etc. For equipment using digital modulation, the FCC Rules also call for a complete description of the modulation method, response characteristics of filters, and a description of the modulating wavetrain.

In some cases, applicants have requested that portions of the application, such as the circuit diagrams and parts lists, be treated as proprietary and withheld from public inspection until delivery of the equipment has begun. The FCC has generally been willing to grant such requests and withhold such information from public inspection for periods of up to two years.

Based on a review of data in the Type Acceptance files, there is one striking conclusion: there is no single industry standard for digital microwave radio design. This is particularly true regarding modulation methods. Of course, FCC Rules impose some standards in the form of channel bandwidths, minimum capacity and frequency stability. Thus, most radios in the 2 GHz band carry 96 voice circuits, but the modulation methods at 2 GHz include: 8PSK, QPSK, QAM, QPR, FSK, and 7 level modified duobinary.

For heavy route digital radios, 8PSK seems to be common at bands up to 12 GHz, and QPSK at 18 GHz. For thin route digital radios in the higher frequency bands, FSK and BPSK have been used.

<u>Point-to-Point Microwave Architectures</u>: Technical requirements which must be met by digital microwave radio systems. include frequency stability, maximum authorized bandwidth, minimum capacity and emission masks.

The assumptions that have been made concerning point-to-point microwave architectures are that all subscriber data is to be routed to one central location in the city, either the CPS station or a ground network central node; point-to-point radios are available at or above subscriber data rates; at the central node the subscriber data interfaces at the port level and the point-to-point radios accept an external clock at one end and "turn it around" at the other.

It is observed that neither demand assignment nor 1:N redundancy is possible with point-to-point microwave radio architectures.

The architectures can be classified by considering two types of subscribers which are those which lie within range of the central location and which have direct line-of-sight (LOS) to it and those which are out of range or have no direct LOS.

Subscribers Within Range and LOS of the Central: For a subscriber located within radio range of the central and having direct LOS to it, a single point-to-point radio link is installed. The central facility provides a clock which the radio "turns around" at the subscriber location. Because of the round trip propagation delay, the received clock at the central radio end may not be in phase with the transmit clock (the clock received from the central switch). This may neccessitate the inclusion of a small smoothing buffer in the central end of the radio. This buffer should not consist of more than a few chips and is assumed to cost less than \$100. The basic configuration is shown in Figure 3.1-10.

The cost of this basic configuration is $C_R + 100$, where C_R is the installed cost of the full duplex point-to-point microwave link.

The above basic configuration can be enhanced in the following ways:

1. Many radios provide a rather primitive interface, e.g., a pair of differential lines. In order to provide a standardized interface to both the central and the subscriber, a pair of interface units needs to be added at either end. Usually these are supplied by the radio manufacturer. The additional cost of this is $2C_I$, where C_I is the installed cost of an interface unit.

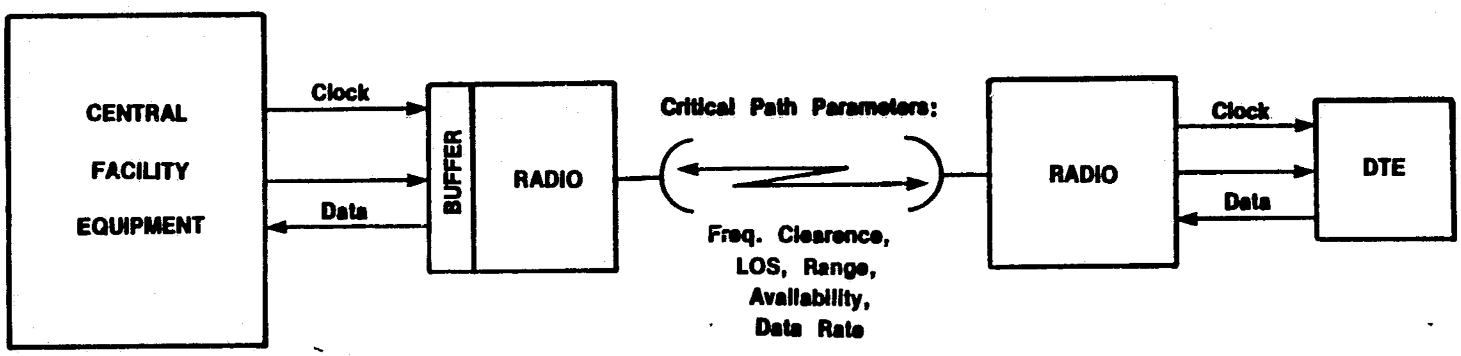

Figure 3.1-10. Basic Point-To-Point Microwave Link Architecture

2. A subscriber may require more than one port. In this case, a mux/demux pair may be added to the above basic configuration. The cost of this option depends on the data rates of the lines that are multiplexed. In any case, it is $2(C_M + C_{MPC})$, where C_M is the cost of a mux and C_{MPC} is the cost of a mux port.

3. Reliability considerations may neccessitate the addition of a 1:1 redundant link, together with an automatic switchover unit. Assuming that the switchover unit costs 10% of the link costs, the cost of adding this feature is $1.1C_R$. It should be noted that many muxes can perform automatic switchover. In this case, the additional cost is taken as $C_R + 0.1\ C_M$.

Subscribers Not Within Range or LOS of the Central: To communicate with subscribers who are not directly accessible from the central node, some kind of repeater is essential. There following are several ways to implement this functional concept:

1. Each far away subscriber has a dedicated link (including needed repeaters) to the central. The additional cost of doing this is NC_{Rp}, where C_{Rp} is the cost of a repeater and N is the number of repeaters required per link.

2. If subscriber #1 is in LOS and range of subscriber #2, then subscriber #2 can act as a repeater. Drop-and-insert muxes are used at the subscriber locations and a point-to-point link is installed between subscribers #1 and #2. If subscribers #1 and #2 also require muxes themselves, then the additional cost of doing this is zero (subscriber #2 is still allocated a basic cost for the mux and the point-to-point radio). This arrangement can include, in a logical tandem, a number of subscribers. Figure 3.1-11 exhibits a configuration which employs dedicated and shared repeaters.

3. If a cluster of subscribers is located far away from the central, then a remote concentrator can be installed. A point-to-point link is installed between the remote concentrator and the central, as well as between each subscriber and the remote concentrator. Figure 3.1-12 is an example of such a configuration.

   Note that arrangements (a) and (b) can also be used by a subscriber to access a remote concentrator.

   The additional cost allocated to a remote subscriber is

$$\frac{C_{RR} + 2C_M}{M} + 2C_{MPC}$$

where C_{RR} = cost of remote link (e.g., T2 Radio)

M = number of subscribers served by the remote concentrator

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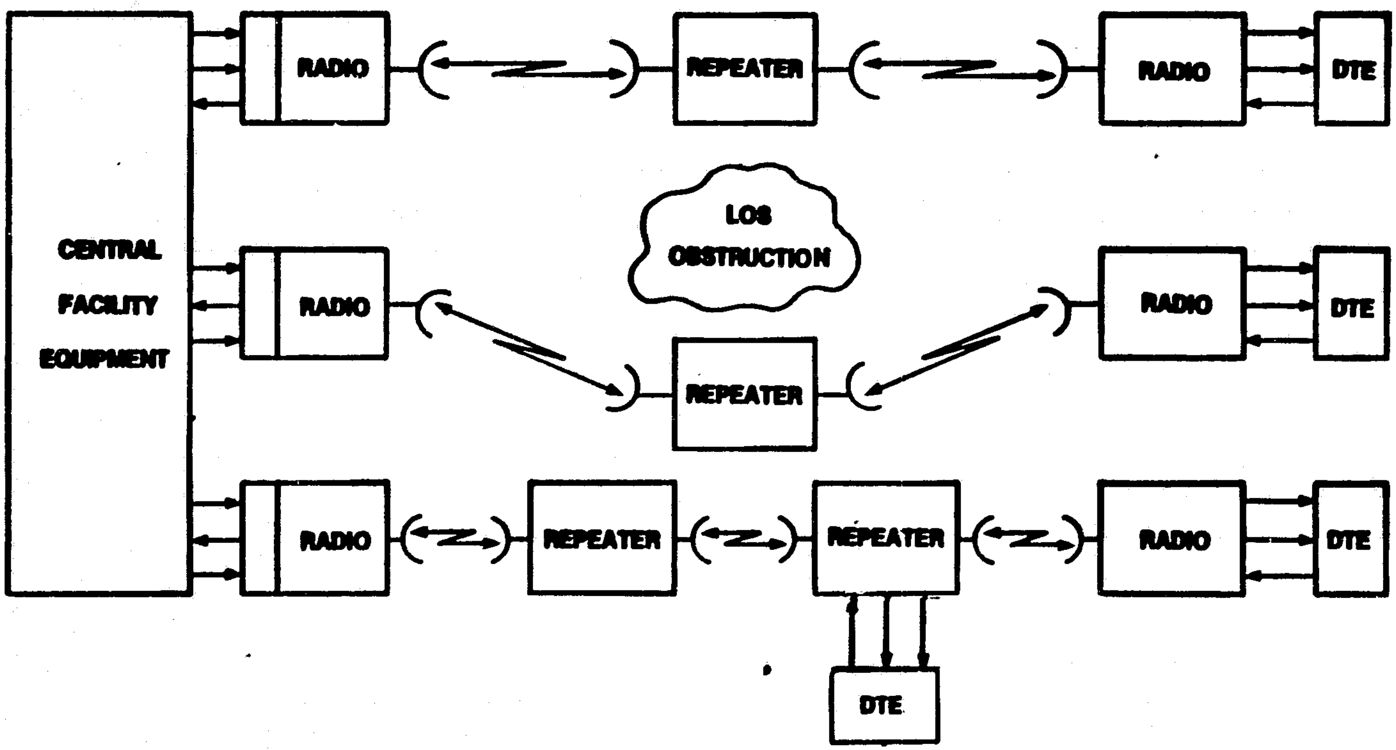

Figure 3.1-11. Point-To-Point Microwave Link Architecture Configured for Distant Subscribers and/or Subscribers Without Direct Line-of Light to Central

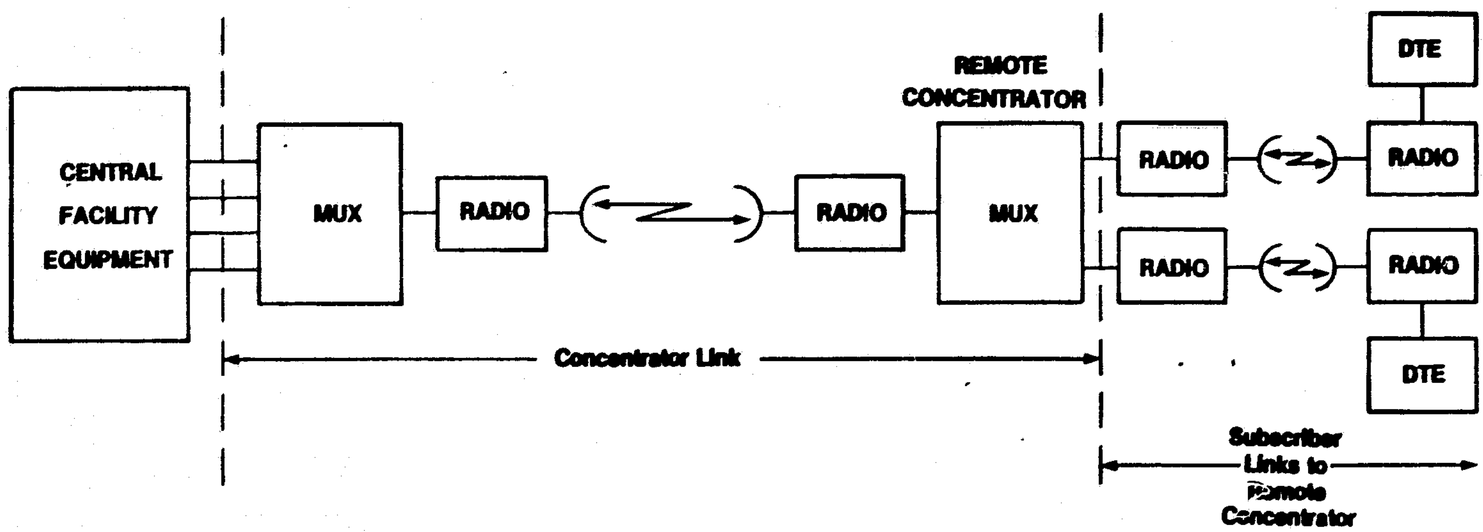

Figure 3.1-12. Architecture for Serving a Cluster of Remote Subscribers

FDMA Architecture: The above discussion assumed that each subscriber requires a dedicated point-to-point radio, and essentially no sharing of equipment is possible (except for the repeater links). The possibility of sharing an antenna and the IF/RF subsystem at the central is also possible (see Figure 3.1-13).

A fan beam antenna is installed at the central facility which, together with the HPA/LNA, is shared by all the subscribers. Figure 3.1-14 is a block diagram of the RF, IF and modems in such a system.

This configuration was compared to installing a point-to-point radio for each subscriber. It is not recommended, however, for the following reasons:

1. The fan beam antenna has a much lower gain than a small parabolic dish antenna (e.g., 16 dBi vs. 30 dBi), which reduces the effective range. Moreover, as fan beam antennas are not off-the-shelf items, a development cost of about $100,000 would have to be incurred.

2. Because of the possibility of intermodulation products, the HPA must be backed off by 6 to 10 dB. For a moderate number of subscribers, the HPA will probably have to be a TWT, costing $30,000 or more. Effectively, then, each subscriber installation costs more with FDMA/SCPC than with dedicated point-to-point microwave links.

However, such a system operated in a TDM/TDMA mode becomes a viable alternative. Figure 3.1-15 is a block diagram of such a system. Note that this is no longer point-to-point links, as each subscriber can gain access to the entire communications channel.

Architecture Selection Procedure: For a given situation, the network configuration to be selected is determined by location of the central node, location of the subscribers, both relative to the central and to each other, and LOS clearance, data rates of the subscribers, and characteristics of the radio links: Frequency clearance; Range/availability; Data Rate

Once selected, the configuration is costed for comparison with the cost of implementing the same network with other transmission media.

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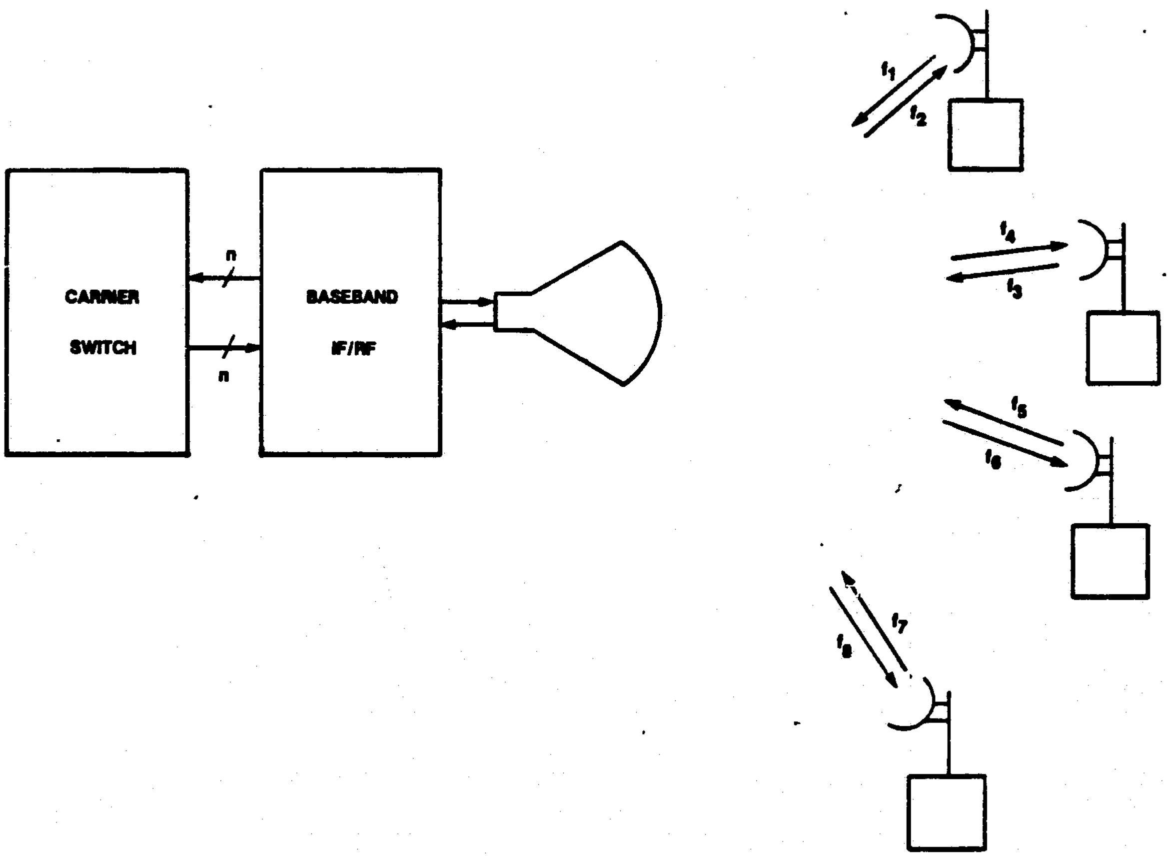

Figure 3.1-13. Shared Antenna at the Central

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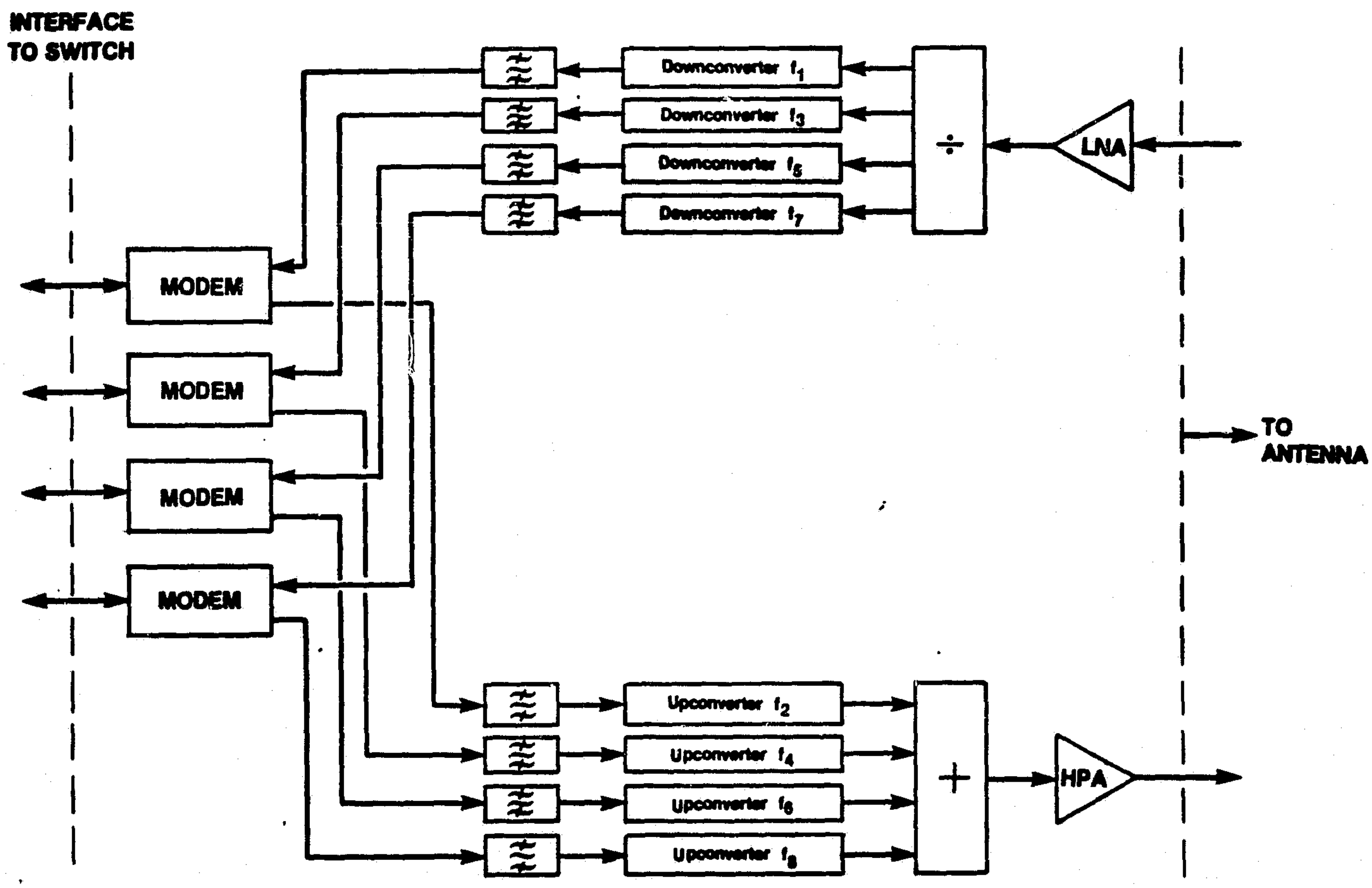

Figure 3.1-14. FDMA RF, IF and Modem Equipment

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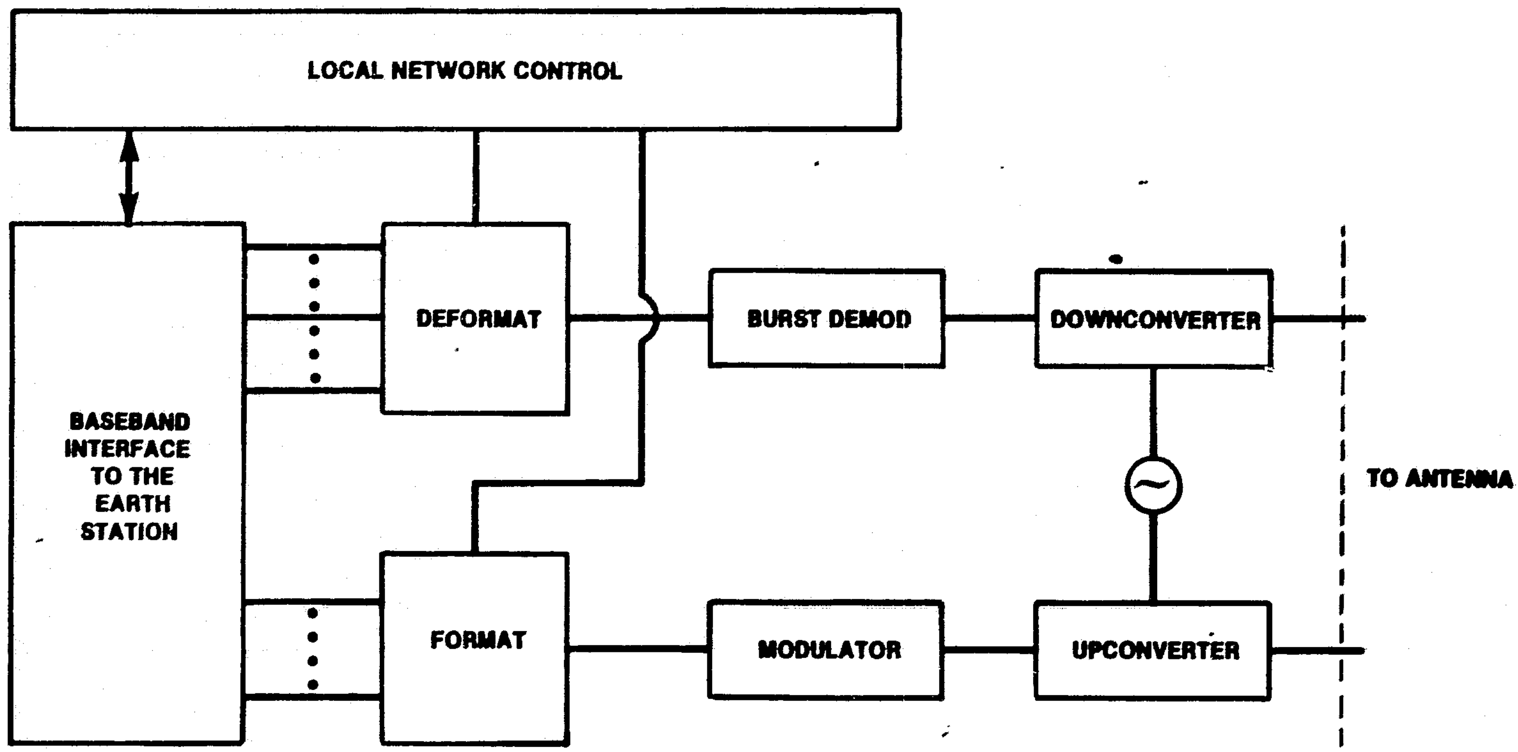

Figure 3.1-15. Point-To-Multi-Point TDM/TDMA

Typical Costs: Given below are some typical costs for non-redundant equipment.

1. C_R = Cost of a point-to-point radio link (i.e., 2 ends)
   \$ 7,000 C_R<\$30,000

2. C_I = Cost of an interface unit
   \$ 400 <C_I \$1,000

3. C_{LM} = Cost of a mux
   \$ 1,000 < C_M \$8,000

4. C_{MPC} = Cost of mux port
   \$ 200 < C_{MPC} \$600

5. C_{Rp} = Cost of a repeater
   \$ 7,000 < C_{Rp} \$30,000
   (same range as basic point-to-point link)

6. C_{RR} = Cost of a remote radio link
   \$20,000 <C_{RR} \$40,000

Point-to-Multipoint Microwave Radio

Another microwave transmission technique, based on cellular radio concepts, employs a combination of line-of-sight microwave radio and multiple access techniques to solve the local and regional data distribution problem. DCC's RAPAC system uses an approach proposed by Xerox Corporation for use in Digital Termination Service (DTS) systems, now approved by the FCC (General Docket 79-188, Petition for Rule Making RM-3247).

In the versions of RAPAC which have been field tested to date, omnidirectional radio coverage is provided from a central station by means of four 90-degree sector antennas, each operating independently on a different frequency channel (see Figure 3.1-16). Within each sector, a continuous carrier is transmitted from the central station which contains Time-Division-Multiplexed (TDM) outbound data addressed to subscribers in that sector. Each subscriber station receives the entire data stream at 260 Kbps and processes it to identify and capture the portion of the data addressed to that station. This data is transferred from internal buffer memories to subscriber terminals at compatible rates.

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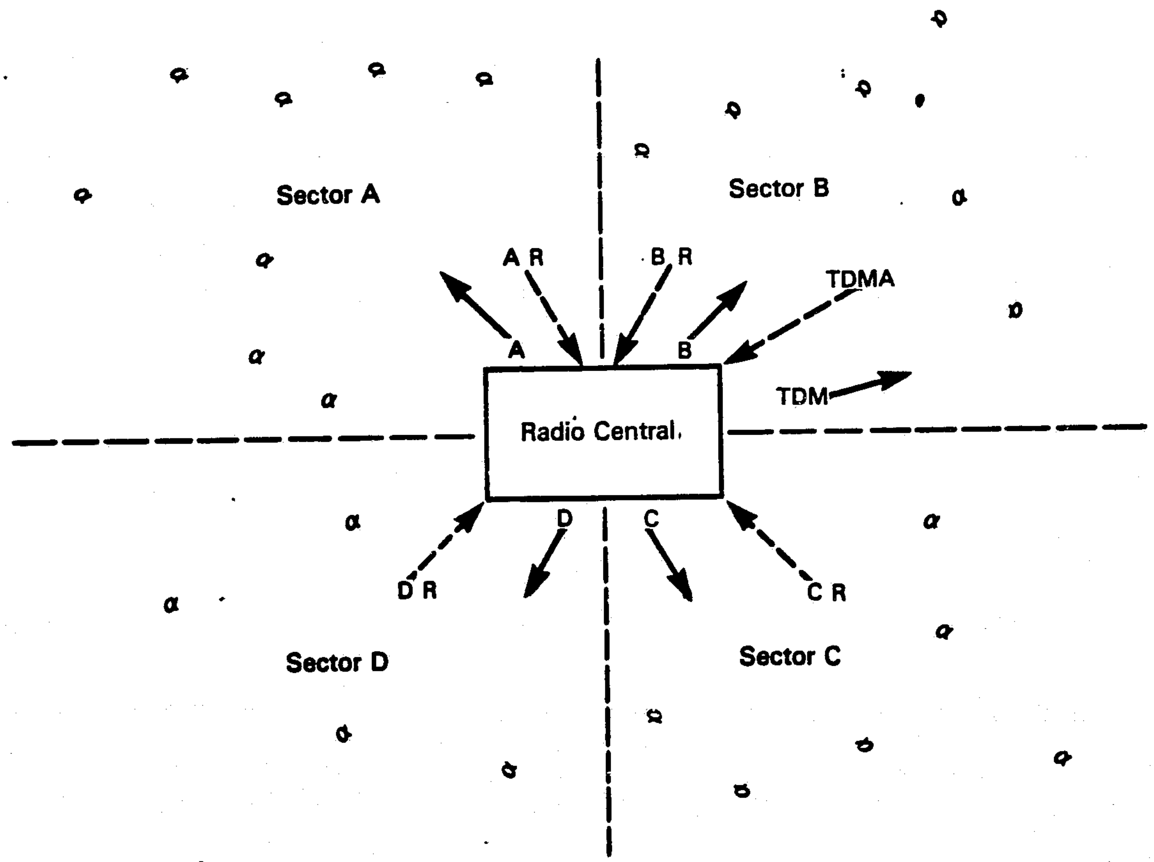

Figure 3.1-16. RAPAC System Operation

For inbound data, the subscriber unit monitors the outbound data stream to decode frame timing information. At appropriate predetermined times, the subscriber unit turns on its radio carrier and begins transmitting data. After a predetermined interval, data transmission is stopped and the carrier is shut off in order to enable other subscribers to transmit.

In this manner a single radio carrier is shared among all of the subscribers in a sector. Each subscriber is capable of transmitting and receiving data through one or more high speed ports (56 kbps) and one or more low speed ports (50 bps to 9600 bps). Up to four subscribers can be served per 260 kbps carrier on this fixed assigned basis if each has a high speed and a low speed port. Figure 3.1-17 illustrates the typical connections between antennas and transceivers for a five carrier (20 subscriber) system.

Frequency Plan: The frequency plan of a typical RAPAC system is illustrated in Figure 3.1-18. This plan follows the approved DTS pattern.

Link Budgets: Some characteristics of the present generation of data transceiver hardware are summarized in Table 3.1-3. These data were combined with existing data on propagation characteristics at 10-11 GHz to derive a link power budget and estimates for the maximum path lengths obtainable. The link budget summary is presented in Table 3.1-4. The maximum path length is obtained on examination of the signal fading mechanisms which predominate.

The radio transmission paths for the local distribution network under consideration are to be generally located in urban environments. The physical size of these urban areas implies that if a centrally-located node is used, the maximum path length is less than six miles. Experience with such paths at similar frequencies indicate that the dominant source of fading for such paths is likely to be rainfall attenuation. Based on this assumption, existing rainfall attenuation models were used to compute the data presented in Table 3.1-5.

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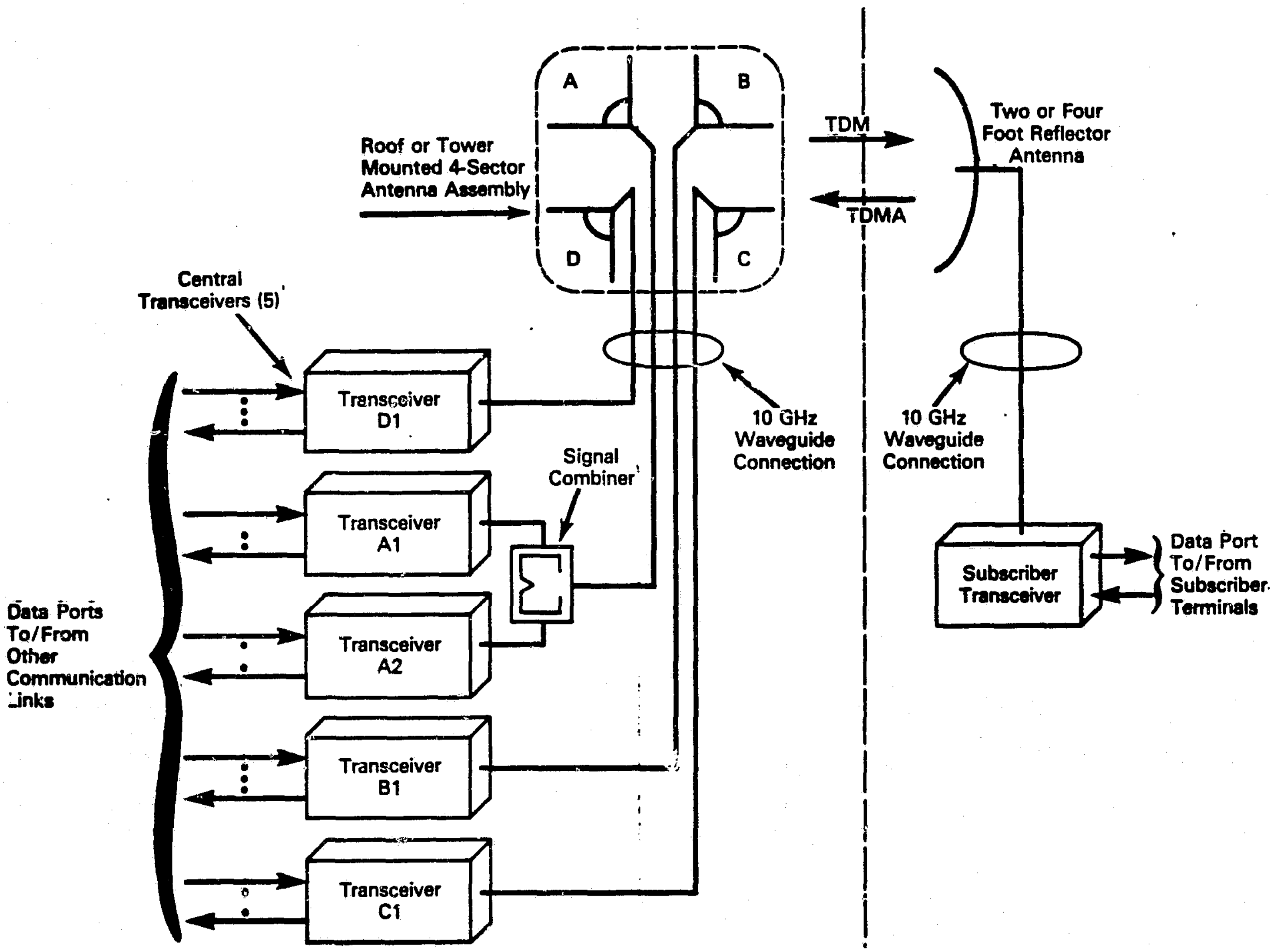

Figure 3.1-17. Transceiver/Antenna Interconnection

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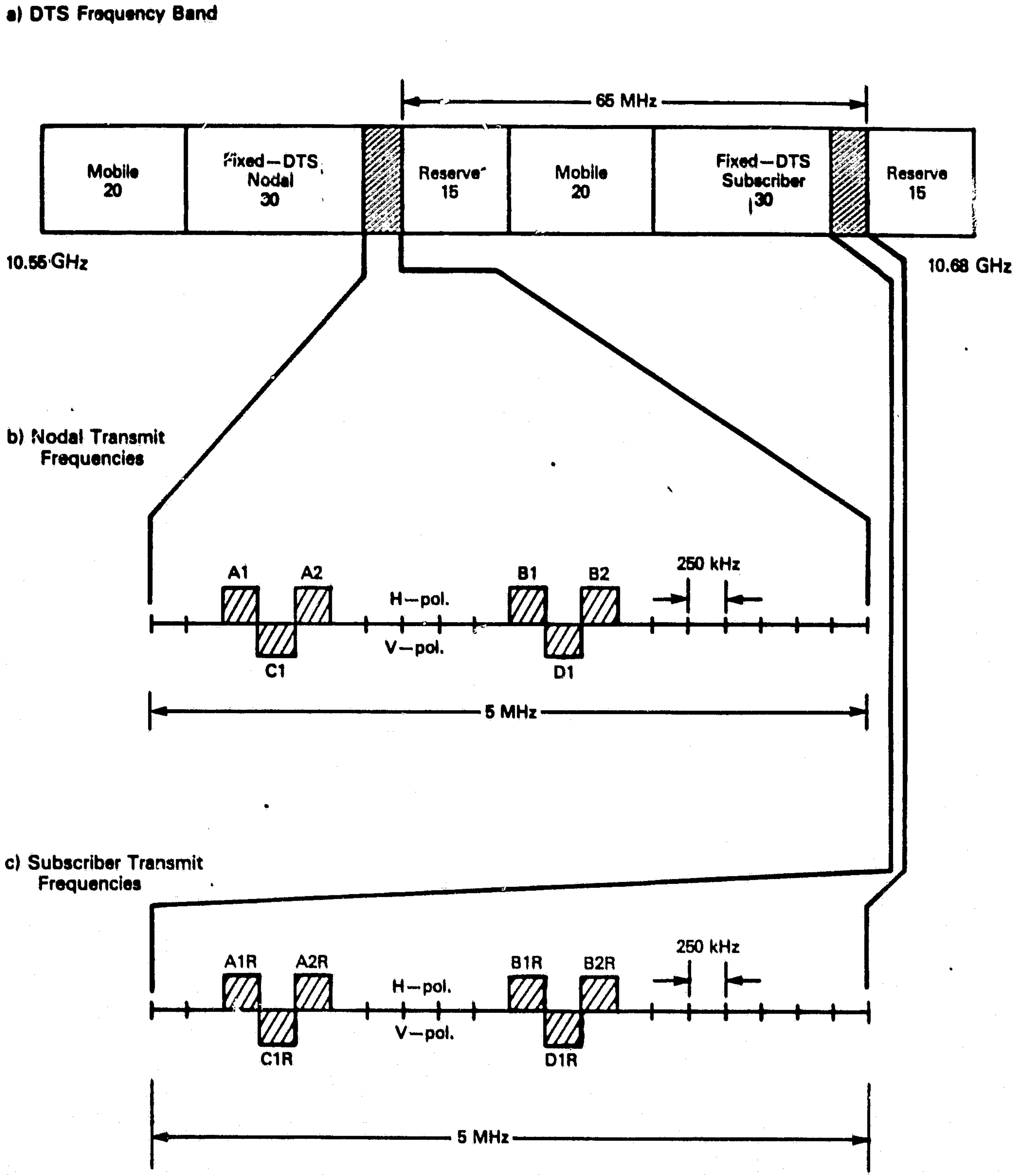

Figure 3.1-18. Typical RAPAC System Frequency Plan

Table 3.1-3. RAPAC System Characteristics

Frequency Band:	10.55 to 10.68 GHz
Channel Spacing:	250 kHz per carrier
Frequency Stability:	.0001% transmit .0005% receive
Type of Modulation	4-level FSK
Modulation Rate:	260 kbps
Power Output:	Central - 0.5 Watt Subscriber - 0.04 Watt
Antenna:	Central - 90-degree fan beam horn Subscriber - Two-foot or four-foot reflector, depending on distance to central.
Transmission Mode:	Central-to-Subscriber - TDM Subscriber-to-Central - TDMA
Frame Time:	60 or 120 ms. factory programmable
Frame Assignment:	Fixed, field programmable.
Number of Subscribers per Carrier	4
BER Performance:	1 X 10^{-8} with at least .9996 availability.

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Table 3.1-4 Typical RAPAC Link Budget Two-Foot Subscriber Antenna

Item	Node-To-Subscriber	Subscriber-To-Node
1. Transmitter Power	27.0 dBm	16.0 dBm
2. Average Power Connection	0.0	0.0
3. Transmitter Loss	0.0	0.0
4. Transmitter Antenna Gain	8.0	34.0
5. Free Space Loss (1 km)	-113.0	-113.0
6. Receive Antenna Gain	34.0	8.0
7. Receivers Losses	0.0	0.0
8. Receiver Noise Figure	12.0	12.0
9. Receiver Thermal Noise (500 kHz)	-117.0 dBm	-117.0 dBm
10. Required C/N (BER = 10^{-8})	18.0	18.0
11. Fade Margin (1 km)	43.0	32.0
12. Link Margin (unfaded)	43.0 - 20 log $R_{(km)}$	32.0 - 20 log
All values in dB unless otherwise specified		
For four-foot subscriber antenna, 1 km Fade Margin increases by 6 dB		

Table 3.1-5. Path Length Calculations

Two-Foot Subscriber Antenna 1 km fade margin				Node-to-Subs. 43 dB	Subs.-to-Node 32 dB
Availability	Outage (min.yr.)	Rain Rate (mm/hr.)	Specific Attenuation (dB/km)	Maximum Path Length (mi.)	
.9996	210	21	.63	15.1	8.9
.9998	105	25	.83	12.7	7.6
.9999	53	30	1.05	10.8	6.7
.99995	26	35	1.28	9.4	6.0
.99999	5.3	60	2.40	6.0	4.1

Four-Foot Subscriber Antenna 1 km fade margin				Node-to-Subs. 49 dB	Subs.-to-Node 38 dB
Availability	Outage (min.yr.)	Rain Rate (mm/hr.)	Specific Attenuation (dB/km)	Maximum Path Length (mi.)	
.9996	210	21	.63	19.05	12.0
.9998	105	25	.83	15.7	10.2
.9999	53	30	1.05	13.3	8.8
.99995	26	35	1.28	11.5	7.8
.99999	5.3	60	2.40	7.2	5.1

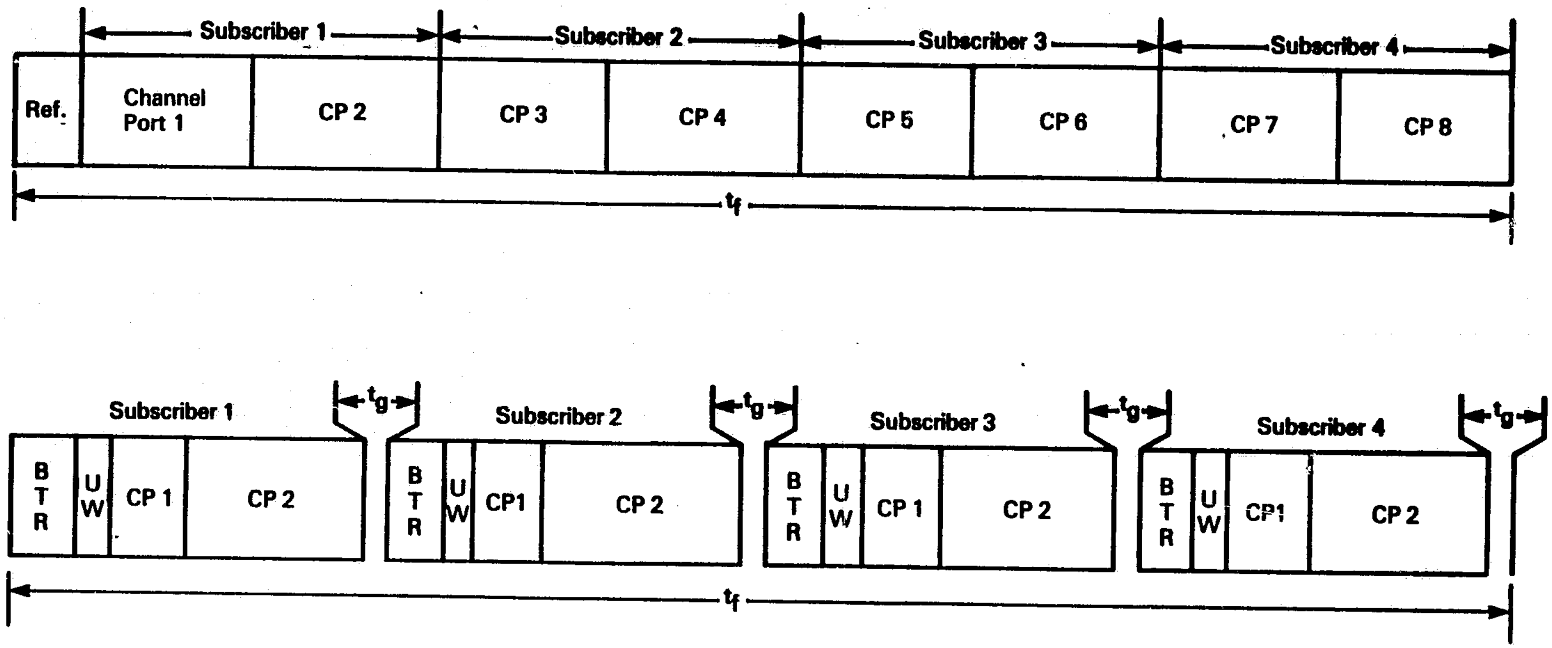
Frame Structure: The present generation of data transceiver equipment operates in a fixed assignment TDM/TDMA mode. The frame structure for these transmissions is shown in Figure 3.1-19. Note that eight "channel port" or user data slots are provided -- two for each subscriber. This frame structure will vary depending on the number of subscriber ports to be connected. The frame will contain one high-speed data slot (56 kbps) and one low-speed data slot (50 to 9600 bps) for each high- and low-speed subscriber data port. The low-speed data ports are programmable to any rate as long as the total carrier bit rate (shared among all the subscribers) is not exceeded.

The total data transmission capacity that is available to each user is limited by the transmission bit rate per carrier, the number of users per carrier, and the system overhead per carrier. Typical values of these parameters are:

Transmission Rate	260 kbps
No. of Subscribers per carrier	4
System overhead per carrier	480 bits/frame

The system overhead is converted to units of bits/second by dividing by the frame time. Results of these calculations showing the number of low speed port bits (assuming that each subscriber has a 56 kbps high speed port) are shown in Table 3.1-6 for several frame times.

The last column of Table 3.1-6 shows the total number of low-speed port bits per second that are available to be shared among the four subscriber stations on a single carrier. These are divided into typical user capacities in Table 3.1-7. For example, the 60 msec frame could provide two subscribers with 9600 bps ports and two subscribers with 2400 bps ports. This would leave 4000 bps of capacity unused. The more-efficient 120 msec frame could provide 9600 bps ports to three subscribers and a 2400 bps port to the fourth subscriber.



Ref.: Reference Unique Word
BTR: Bit-Timing Recovery (40 Symbols, 80 Bits)
UW: Unique Word (10 Symbols, 20 Bits)
t_g: Guard Time (10 Symbols, 20 Bits)
t_f: Frame Time (60 or 120 msec, Variable)
TDMA Overhead = 4 x (BTR + UW + t_g) = 4 x (80 + 20 + 20) = 480 Bits Per Frame

Figure 3.1-19. Typical RAPAC TDM/TDMA Frame Structure

Table 3.1-6. TDMA Overhead Calculations - Single Carrier, 260 kbps

Frame Time (msec)	System Overhead (bits/frame)	System Overhead (bits/sec)	User Data Capacity Total (bits/sec)	User Data Capacity High Speed (bits/sec)	User Data Capacity Low Speed (bits/sec)
60	480	8,000	252,000	224,000	28,000
120	480	4,000	256,000	224,000	32,000

Table 3.1-7. Typical Maximum Low Speed Data Port Rates

Frame 60 msec.

No. of Low Speed bits per second - 28,000

Port Combinations (bits/sec)

2 - 9600 2 - 2400	or	2 - 9600 1 - 4800 1 - 2400
Unused - 4000		Unused - 1600

Frame 120 msec.

No. of Low-Speed bits per second - 32,000
Port Combinations (bits/sec)

3 - 9600 1 - 2400	or	2 - 9600 2 - 4800
Unused- 800		Unused - 3200

Transceiver Equipment - Subscriber Station: The subscriber station consists of a single transceiver which is composed of two units: a digital portion and a RF/modem portion (see Figure 3.1-20). The digital portion contains a controller, a high-speed port and a low-speed port. These two ports correspond to two identical ports at the central station.

The data rate on the low-speed port can be programmed for any rate between 50 and 9600 bps as long as the maximum aggregate bit rate per carrier is not exceeded. (As described above, the link capacity available for low-speed data will support up to three 9600 bps ports and one 2400 bps port per carrier if a 120 msec frame is used.)

As illustrated in Figure 3.1-21, the subscriber terminal consists of three distinct pieces of equipment, the TDM/TDMA Controller and Data Ports, the RF Equipment and Modem, and the Antenna.

The TDM/TDMA Controller performs all of the multiplexing and network synchronization functions. The Data Ports serve as high speed (56 kbps) and low speed (50 bps - 9.6 kbps) business machine data input/output interfaces.

The RF Equipment and Modem Interface with the Controller and perform the functions of four-level FSK modulation/demodulation and up/down conversion to/from microwave frequencies.

The antenna is a commercially available 2-foot parabolic reflector which may be mounted on a 2" pipe, or a tripod.

Figure 3.1-22 is a block diagram of a subscriber terminal. It should be noted that the baseband parts of all subscriber terminals are identical; the radio-frequency parts are tunable with the possible exception of the radio-frequency filters. This feature of the equipment design economizes on spares and ensures that, as the system expands, spares may be deployed to serve new subscribers on demand; spare holdings can then be replenished in economical batches rather than piecemeal.

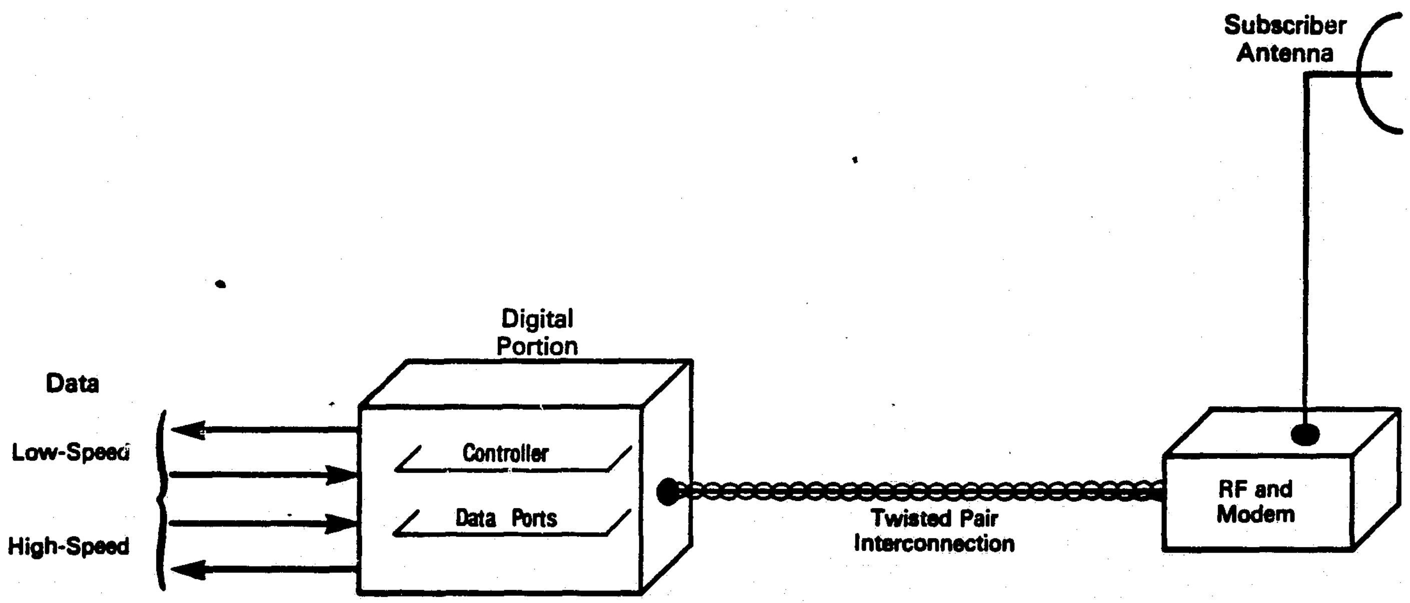


Figure 3.1-20. RAPAC Subscriber Transceiver

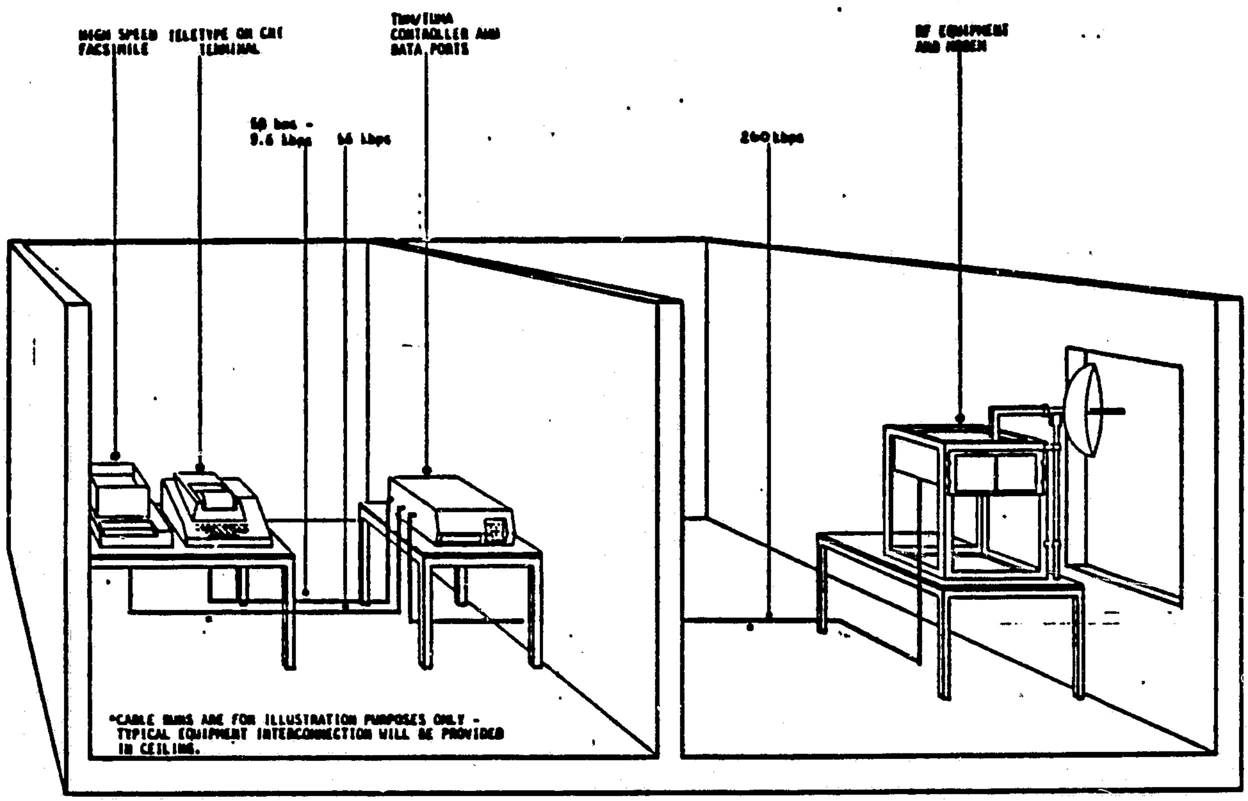


Figure 3.1-21. Pictorial Presentation of a Typical RAPAC Subscriber Terminal

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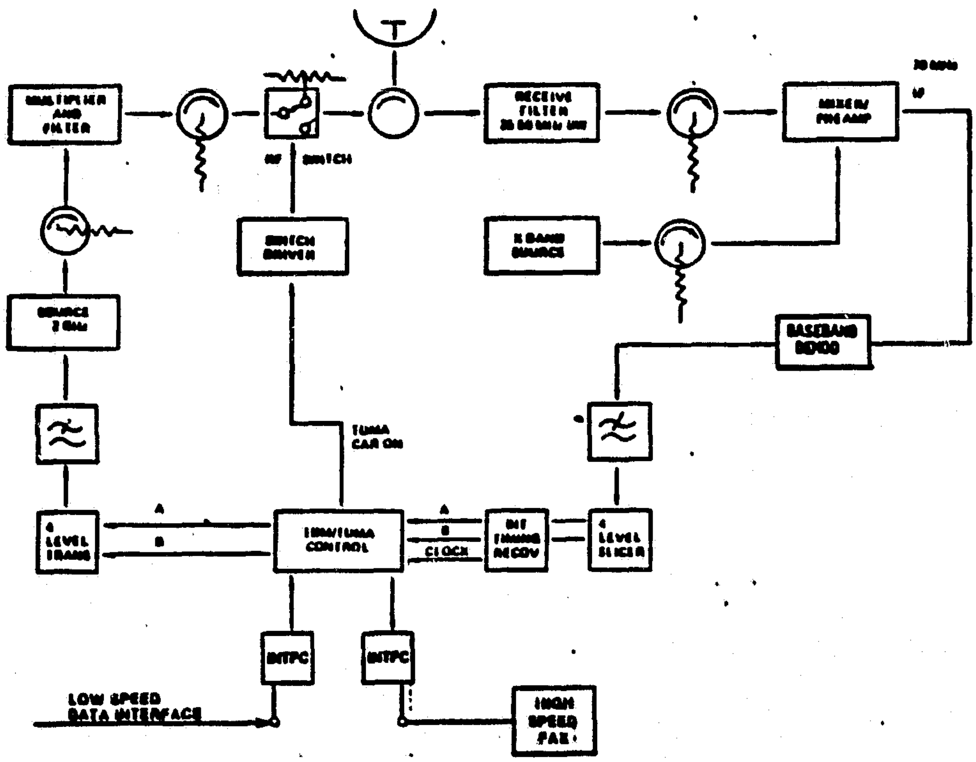

Figure 3.1-22. RAPAC Subscriber Station Block Diagram

The heart of the subscriber station transmitter is a microwave source followed by a solid state multiplier.

The incoming signal from the transmit/receive antenna passes to a receive radio-frequency filter and then to the receiving mixer/preamp. The mixer preamp utilizes an X-band source to translate the spectrum to 70 MHz IF. The amplifier is designed to accept signals over an input range of approximately 40 dB. The signal is then sent to a four level FSK demodulator. A four-level slicer delivers two data streams to the bit timing recovery circuit. From this, the time reference is recovered and used to lock the TDM/TDMA control circuits.

On the transmit side, the incoming digital stream from the interface circuitry is sent to a compression buffer within the data port circuit. This buffer delays the low rate digital data from the interface and reissues it in burst format at the appropriate rate and time as defined by the TDMA frame.

The bursts of binary digits are translated to four levels, spectrum-limited by a lowpass filter, and used to directly modulate the source frequency. The modulated source signal is then multiplied by a solid-state amplifier to its final RF frequency.

Both transmitter and receiver are coupled by ferrite circulators to the waveguide feeder and then to the T/R antenna. The type of antenna selected for both T/R applications is a 2-foot parabolic reflector, (or possibly 4-foot antenna, depending on distance).

The main characteristics of the subscriber's terminal are found in Table 3.1-8.

Transceiver Equipment - Central Station: The central station typically contains one or more radio central transceivers, plus one spare, each with four high-speed and four low-speed ports (shown previously in Figure 3.1-17). The data streams from these ports are fed to a communications processor which multiplexes and demultiplexes the data. This processor takes the form of a channel bank if the data are time-division multiplexed, or to independent data circuits.

Table 3.1-8. RAPAC Subscriber Transceiver Characteristics

Maximum Range:	5 to 10 miles (typical 6 miles)
Bit Rate:	260 kbps
Frequency:	10.55 - 10.68 GHz
Transmitter Frequency Stability:	1×10^{-6}
Transmit Power:	40 mW minimum
Antenna:	2-foot parabolic reflector (or 4-foot if required)
Modulation:	Four-level FSK
Spectrum Utilization:	1.0 Bit per Hz (Aggregate)
Receive Mode:	TDM
Transmit Mode:	TDMA
Interface:	1) 56 kbps high-speed fax 2) Low-speed data port programmable for 50 - 9600 bits/sec.
Supervisory:	Alarm indicators for synchronization failure
Alarm Functions:	Carrier on timeout
Power Dissipation	Less than 100 W
Temperature Range:	+10 to +40°C

The digital portion of the central transceiver (see Figure 3.1-23) is organized into chassis which contain a controller and a number of ports. Present design provides one high-speed and one low-speed port per circuit card. The central transceiver contains one port for each subscriber port. Thus, if four subscribers are connected, each with a high- and low-speed port, eight ports or circuit cards will be required at the central.

If more than these eight ports are required, additional ports may be provided.

The basic design of the radio frequency part of the central station is similar to that of the subscriber's terminal. However, to ensure that the timing of the TDMA return circuits is held correctly by all subscribers under all but the most adverse conditions, the central station radiates more power (approximately 500 mW).

Because the central station transmitter/receiver is common to all subscribers on its radio frequency channel, the equipment may be duplicated for redundancy. Twin transmitters may be coupled via a solid-state hot-standby switch to the antenna; twin receivers may be coupled to the antenna via a 3 dB hybrid circuit.

The arrangement of the antennas will depend on the physical distribution of initial or potential subscribers. For a typical system, the central antenna is a multiple Fan-Beam Horn with each sector covering 90°. Ultimately, each antenna can carry several T/R carriers on particular radio-frequency channels. To conserve spectrum space, alternate channels will be cross-polarized.

The central equipment is similar to the subscriber unit, with the exception that the RF Equipment and Modem are housed in two chassis to accommodate higher output power and TDMA demodulator circuitry. Because the incoming carriers are from multiple subscriber transmitters, the four-level demodulator has a tracking circuit to account for dc components in the demodulated signal due to burst-to-burst frequency differences between the TDMA carriers.

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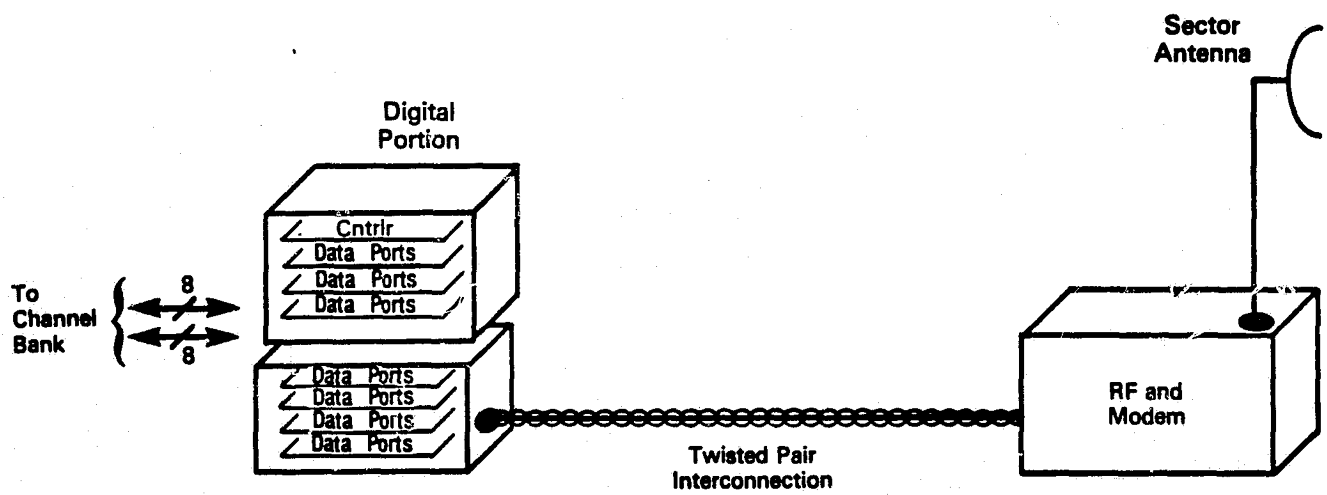

Figure 3.1-23. RAPAC Central Transceiver

The TDM/TDMA control circuits generate the primary timing for the control station and all the subscriber's equipment. The incoming 260 kbps TDMA stream is divided into frames which are then demultiplexed to give continuous signals before passing to the interface circuit for subsequent low-speed port output transmission.

Each set of TDM/TDMA equipment associated with a particular radio-frequency channel is identical to those associated with other channels, the principal difference being crystal frequencies to discriminate sectors. An alarm indicator for each port indicates proper reception of subscriber data. Each subscriber's channel will have a lamp; these will be in a viewing panel which can be extended as more subscribers are needed. The main characteristics of the central terminal are summarized in Table 3.1-9.

Table 3.1-9. RAPAC Central Transceiver Characteristics

Maximum Range:	5 to 10 miles
Bit Rate:	260 kbps
Frequency:	10.55 - 10.68 GHz
Carrier Frequency Stability:	1×10^{-6}
Transmit Power:	500 mW
Antenna: Fan-Beam Horn; Horizontal Polarization; Beamwidths (3 dB) Az = 90°, EL = 6°; Gain = 16 dBi;	
Modulation:	Four-level FSK
Spectrum Utilization:	1.0 Bits per Hz (Aggregate)
Receive Mode:	TDMA
Transmit Mode:	TDM
Interface: 1) 56 kbps high-speed FAX 2) Low-speed data programmable from 50 - 9600 bps	
Supervisory:	Alarm indicators for loss of synchronization
Power Requirement:	100W
Temperature Range:	+10 to +40°C

General Point-To-Point Guided Media Requirements

The following assumptions have been made concerning point-to-point guided media archetictures:

1. All subscriber data is to be routed to one central location in the city.

2. At the central node, the subscriber data interfaces at the user port level.

3. The RF or optical modems accept an external clock (long haul carrier clock) and use it for transmission in both directions.

4. Any common carrier employing guided media would require dedicated paths. For example, a carrier who transmits digital data would most likely not be willing to share bandwidth with entertainment distributors. This is due to poor cable maintenance which affects reliability, maintainability, and noise factors.

It is observed that:

1. Demand Assignment within the transmission media is not possible with point-to-point guided media archetictures.

2. 1:N redundancy is not possible.

In the United States, there are approximately 4000 CATV systems generally located in smaller cities and towns, or on the peripheries of large metropolitan centers. CATV systems range in size from fewer than 2,000 subscribers to over 100,000. CATV penetration is lowest in large cities, where new services are most likely to begin, and greatest in rural areas and smaller cities, where over-the-air TV reception tends to be limited in the number of available channels. As of December 1975, CATV penetration of TV homes in the top 10 markets, generally corresponding to the 10 largest urban areas in the United States (i.e., New York down to Pittsburgh), was just over 10%. In markets 11 through 50 (i.e., Dallas-Ft. Worth down to Greensboro/Winston Salem, N.C.), it was also approximately 10%. In markets ranked 51 through 100 (i.e., Salt Lake City down to Fargo, N.D.), it was approximately 15%, but in markets smaller than the first 100, CATV served 25% of all homes.

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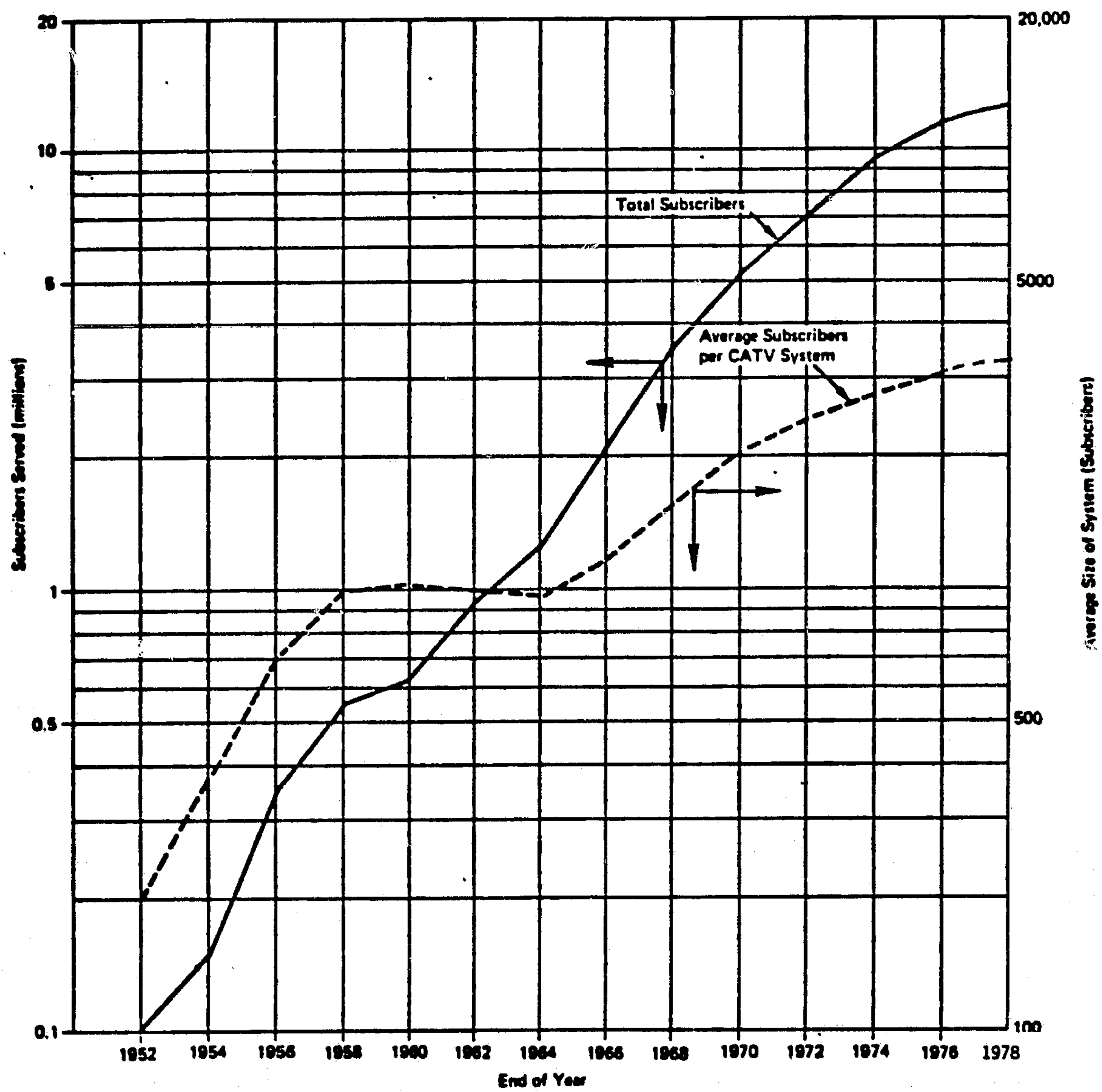

Source: TV Factbook

Figure 3.1-24. CATV Growth

The graph of Figure 3.1-24 shows that the average size of CATV system is steadily growing. The increase reflects, in part, the fact that much CATV growth represents enhanced penetration by current systems and, in part, that systems are now being constructed in larger markets. As of 1977, fewer than a fourth of the 3800 systems served more than 3500 subscribers, of which fewer than 70 systems (2%) served more than 10,000. Such systems reached roughly two-thirds of the industry's 11.9 million subscribers.

Major market CATV systems tend to be located on the edges of the areas served rather than in the centers. One reason is that they can improve TV reception in the suburbs and exurbs (which are defined as being within a market area designated by the name of the city at the core). Another reason is that construction of the CATV plant is less costly in the outlying communities, which tend also to be more affluent and to present less forbidding political obstacles to CATV construction.

A typical cable television system has a head-end, usually including a large tower-mounted antenna, a coaxial cable distribution network of trunks and feeders through the developed portion of the franchise area, thousands of coaxial cable drops (one for each subscriber) and often set-top devices, called "converters." The antenna and head-end equipment capture TV broadcast signals from the air and process them for retransmission over the coaxial cable network. In the subscriber's home, set-top converters enable reception of an expanded range of channels.

<u>Inherent Capability of the Medium</u>: Cable TV head-ends are generally located at a distance from population centers. The signals are transported over a trunk cable system which consists of a large coaxial cable, usually between 3/4 in. and 1 inch in diameter, and a series of main trunk amplifiers. Coaxial cable is an appropriate transmission medium at frequencies from a few MHz through the VHF band. Until the mid-1960's standard cable TV transmission involved placing conventional vestigial sideband broadcast VHF television signals on the cable and amplifying the signals with repeaters at regular intervals.

The usable portion of a coaxial cable transmission system is limited to about 400 MHz. Most U.S. cable television systems still provide between 6-12 TV channels, but there also now are many which provide more than 20 channels. Technology is available to create CATV systems with 50 or more channels. This is done by placing channels in VHF band frequency space not normally assigned to TV broadcasting. Broadcasting VHF TV channels fall in the following bands:

Low VHF (channel 2 through 6): 54-88 MHz
High VHF (channels 7 through 13): 174-216 MHz.

The additional channels are placed between channels 6 and 7, and above channel 13.

Broadband amplifiers spaced at regular intervals along the coax cable must: provide amplification to make up for cable loss, insert equalization to make up for variation in cable loss across band, and insert regulation to make up for variation in cable loss, particularly with temperature changes.

Requirements on CATV are very stringent, and, while superb amplifiers are available, the degradation introduced by a string of amplifiers is cumulative and limits system length.

Some typical values of attenuation, in dB per hundred running feet, are given in Table 3.1-10.

Architecture: The two basic configurations of CATV distribution systems are generally designated as trees and hubs. The cable arrangement with trunks and feeders radiating from the head end is a basic tree formation in which all programs go to all subscribers over the same trunk cable. When interest in two-way CATV developed several years ago, however, the tree layout was perceived to have serious disadvantages. One particular problem is that all of the noise gathered on all of the branches in the reverse (i.e., upstream) channel accumulates in the trunk. This problem can be decreased by use of hub systems - systems in which a trunk connects to one or more hubs from which all signals are propagated on radial spokes, delivering programs to all subscribers on a party-line basis.

Other advantages of hub systems are possible reductions in the number of amplifiers in cascade with resultant improved performance; increased availability of upstream channels; reduced total signal noise return on upstream channels; and some localism, which is possible because programs originated at the head-end can be patched into the trunk cable serving only one section of the community. On the negative side, duplicate trunk cable often used to carry signals between the head-end and distant hubs can add to costs. We foresee a shift to forms of hub arrangements in new CATV systems because of the net benefits available, and because of the two-way potential.

Table 3.1-10. Typical Coaxial Cable Losses (in dB/100 ft.)

Cable Diameter	Term	50 MHz	220 MHz	1000 MHz
.5"	Conductor	.532	1.117	2.390
	Dielectric	.033	.149	.670
	Total	.565	1.266	3.060
.75"	Conductor	.358	.752	1.610
	Dielectric	.033	.149	.670
	Total	.391	.901	2.280

At the end of the distribution system a tap or splitter is used to connect a drop cable (that is, the individual connection to a subscriber) with the distribution cable. Taps are commonly provided for one to four drops and must be selected so that a standard level is provided at each subscriber's location. The tap isolates the drop cable from the distribution cable so that if one subscriber's equipment becomes short-circuited or produces spurious signals it will not affect the signal going to other subscribers.

New inventions or technological advances are not required for two-way CATV; all that is needed is a way to make it economically viable. Current FCC regulations require that new cable systems in a top-100 market have plant which has the "technical capacity for non-voice return communications." The "return communications" refers to signals flowing upstream, in the opposite direction from the bulk of cable-cast material. "Non-voice" capacity is generally interpreted to mean limited, narrowband data capability. The industry commonly interprets "technical capacity" to mean that new installations should not preclude eventual two-way transmission. Return transmission capacity may be provided in several ways:

1. Pairs of wires can be put in the same sheath as a coaxial cable, or strung with it, or even leased from the telephone company.

2. An additional separate coaxial cable can be run in the upstream direction.

3. Two-way repeaters can be installed in place of the conventional one-way amplifiers. These repeaters use filters to separate frequency bands into two directions. Typically, the normal 54 to 400 MHz band is used for downstream TV and FM, while the return direction uses the 5 to 30 MHz band. All major CATV suppliers make repeaters for this application. Often these can be retrofitted on a plug-in basis.

Since a large part of the installed cost of a CATV system consists of labor, it may be economical in the long run for operators to string two cables and postpone equipping the upstream cable with electronics until a real need emerges. A complete dual-cable system offers the greatest return-channel capacity and has the virtue of technical simplicity, but it also costs the most. The use of wire pairs for return channels is simplest and least expensive but is relatively inflexible and offers limited bandwidth.

The cable industry is reluctant to commit itself to a single type of system because of a lack of encouraging or definitive results from two-way experiments. A number of two-way systems have been started in recent years. These experiments have been widely publicized, but most ceased when the external money supporting them was withdrawn.

Data Transmission Over CATV: Like two-way services, high-speed data transmission via cable is technically feasible now but has not been extensively exploited. The considerable amount of bandwidth available in a CATV coaxial cable is often under-utilized. The technology exists for using the bandwidth quite effectively for transmitting data along with regular video signals. Some possible applications are:

1. Leased broadband channels for high-speed data transfer, as used on Manhattan Cable in New York City. Such uses generally require reverse channel transmission capacity, which can be provided by either two-way cable or alternative geographical paths.

2. Digitized voice transmission using either telephone PCM carrier equipment or an encryption device.

3. Encrypted, digitized video transmission. However, perhaps as many as five CATV channels might need to be sacrificed to provide one encrypted video channel.

The technical problems involve providing a sufficiently high data capacity without degrading the remaining video channels. Technology is now available for satisfactorily replacing one TV channel with up to four 1.5-megabit pulse streams.

Custom Routed Cable: If existing cable facilities do not conveniently serve the desired subscriber sites, the option may exist to custom route cable, either under or above ground. Coaxial cable can be routed in this way to provide high speed digital transmission.

For a given design of coax cable (i.e., given D/d ratio, dielectric, protective covering, etc.) the cost beyond the smallest cabletends to vary as the square of the diameter. Since repeater cost per mile varies as 1/D and the coax cost varies as D^2, there is a distinct economic optimum where the total cost function is a minimum. In order to transmit over even the modest distances encountered in most CATV systems, an economic penalty in favor of cable costs has been made. The economic penalties of increasing distances by further increasing cable costs are considerable.

Cable costs vary widely, but the data in Table 3.1-11 represents a crude estimate of current costs per mile.

Table 3.1-11. Representative Urban CATV Construction Costs[a] ($/strand mile)

	Aerial	Underground
Transmission Hardware	3,500	3,500
Converters[b]	2,900	2,900
Construction	3,900	7,800 - 27,000[c]
Total	10,300	14,200 - 33,400
Cost/Subscriber[c]:	128	$178 - $ 418

Source: U.S. Department of Commerce, Office of Telecommunications

[a]One way, single cable, 30-channel system adaptable to two-way service
[b]Assumes 80 subscribers per strand mile
[c]Depends on nature of surface (paved or unpaved), soil type, type of conduit vs direct burial

Two way transmission adds about $5,000 to the electronics cost of the head end. If a computer is installed as "traffic manager" at the head end, costs begin at around $50,000 and rise with the need for larger memory capacity and more sophisticated software.

Point-to-Point Coaxial Cable: As is the case for point-to-point microwave radio archetictures, point-to-point cable modems may be operated in two ways for local data networks. One mode calls for the coaxial cable data link to provide each subscriber with direct access to the central facility. The other mode of operation would serve to concentrate several users (by using multiplexers) onto a higher rate point-to-point link to the central node. In this way, a cluster of users could share a link to the central node.

This remote-to-central node link need not be restricted to coaxial cable, but could be any of the point-to-point link media discussed in this report. Link sharing could produce cost savings for all subscribers in the cluster when compared with individual remote-to-central node links for each subscriber.

Coaxial Cable Modems Serving as Point-to-Point Links from Remotes to the Central Node: This architecture is only slightly more complicated to implement than point-to-point digital microwave radio due to the need for installed coaxial cable plant between the remote and the central node. A diagram of such a link may be found in Figure 3.1-25. Note the essential similarities when compared to a point-to-point digital radio link.

As mentioned previously, the common carrier providing local distribution would most likely desire a dedicated cable plant. Some of the more critical reasons for this include the typically marginal maintenance of CATV distribution plant, the accumulation of noise in the upstream direction of a bi-directional plant that is a result of the proliferation of unmaintained taps in the system, and the current difficulty in renting bandwidth on a monthly basis.

Additionally, there are not very many fully bi-directional cable plants presently in service.

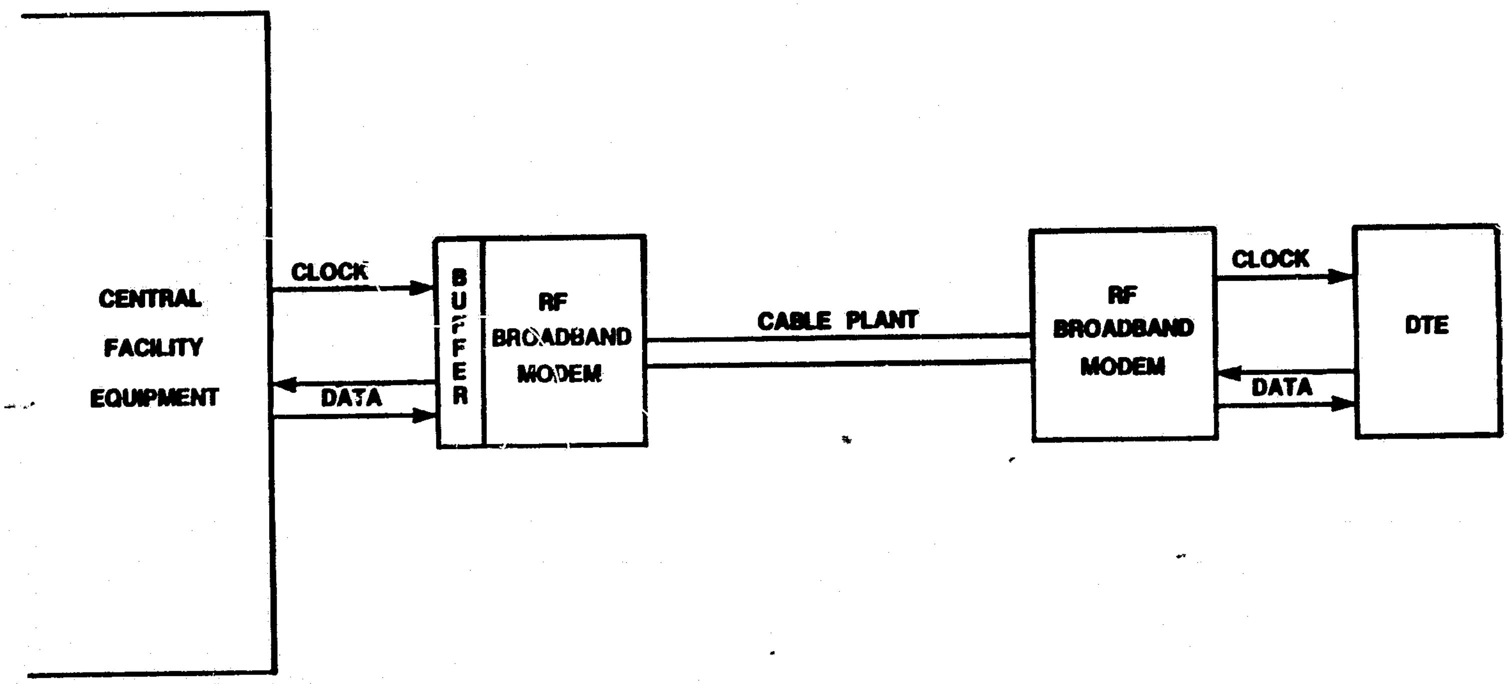

Figure 3.1-25. Typical Point-To-Point Coaxial Cable Link

One advantage of a coaxial cable plant over the other major guided medium, fiber optic cable, is that one multi-tapped cable can be used to economically serve many non-collocated subscribers, whereas an additional central to subscriber path or an expensive repeater tap must be added for each fiber optic subscriber. This reduces the total installed cable mileage and allows for more efficient use of the cable bandwidth.

An additional consideration for these point-to-point links is the repeater amplifier spacing used in the coaxial cable trunking system. Typical spacing is on the order of 1200 to 2000 feet. Exact spacing will depend upon the operational gain of the amplifiers selected. Additionally, unrepeated operation is possible for distances of up to 2 km. This potential for unrepeated operation is ideal for the application discussed below.

Coaxial Cable Serving As a High Rate Link Between a Remote Concentrator and the Central Node: In this implementation mode, a cluster of remote subscribers share transmission facilities to the central node, see Figure 3.1-26. This cluster may be located within a building, a campus-like environment, or a large business park. Given ideal circumstances, substantial savings could be realized in this way, as there are many costs associated with the remote-to-central link which are independent of the transmission rate. These include installation, mounting equipment, and clearance and filings.

The type of coverage that is required for the remote area concentration corresponds to many local area networking products on the market today.

Architecture Selection Procedure: The key factors leading to the selection of guided media archetictures include cost comparison with microwave, availability of rights of way of the cable or fiber, location in an area not suitable for microwave links, difficulty in obtaining clear lines of sight, and frequency clearance problems.

The primary obstacle preventing the widespread installation of both fiber optics and coaxial cable links is the problem encountered in obtaining rights of way for the cable. Obtaining conduit space or permission to string cable on telephone poles will most likely result in a high monthly rent, which could destroy any competitive advantage such coaxial cable transmission would

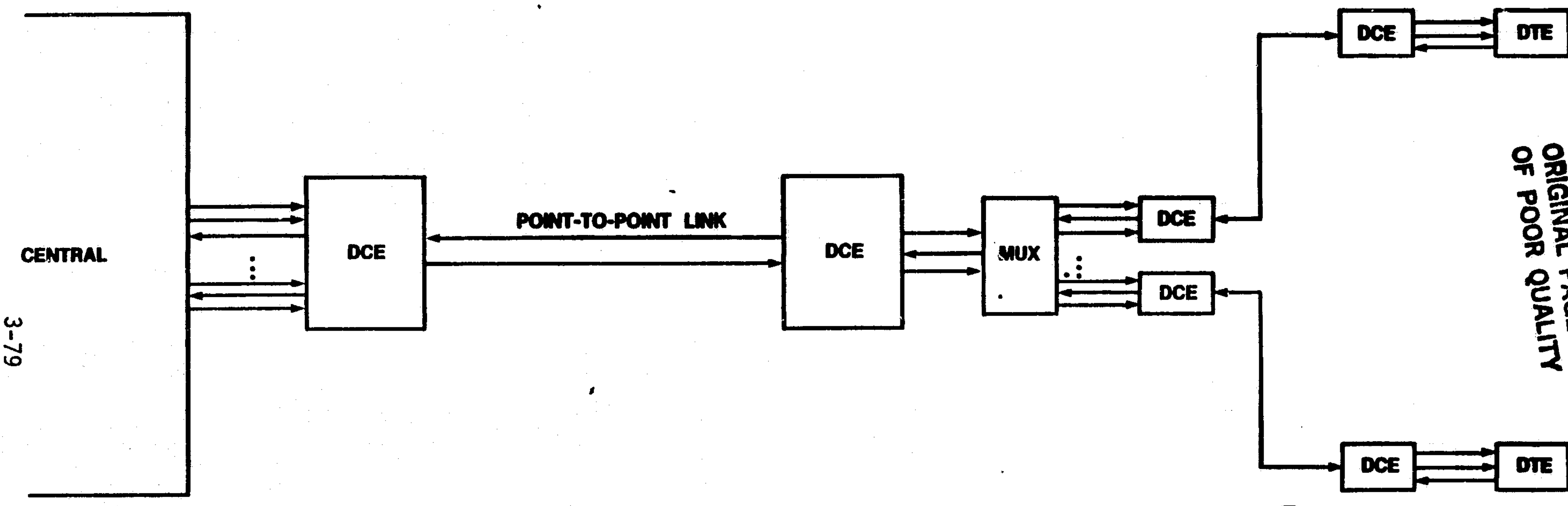

Figure 3.1-26. Coaxial Cable Serving as Remote Concentration Link

offer. Rents are set by the cable operator or the owners of rights of way based upon their perception of the value of the resource. Due to the extreme wide range of possible rental agreements, such rents have been treated as exogenous costs, applicable to all guided media archetictures, but not readily predictable.

Typical Costs: The typical cost elements for a coaxial cable point-to-point link are given below:

1. Cost of a low rate (below 19.2 kbps) RF modem - $300 to $1,000
2. Cost of a high rate (56 kbps to 6.312 Mbps) rf modem - $3,000 to $5,000
3. Cost of smoothing buffer - $100
4. Installed CATV plant costs (aerial) - $9,000/mile
5. Coaxial cable tap - $75 to $100

Point-To-Multipoint Coaxial Cable

As has been previously pointed out, savings can be realized by concentrating several DCEs onto one coaxial cable. The example previously discussed utilized the cable in an FDMA point-to-point fashion. This is an attractive alternative for sparsely subscribed systems. But, as the number of connected users increases, the proliferation of modems at the central site becomes expensive and unwieldy.

In this scenario, a point-to-multipoint architecture becomes more practical. The access protocol which results in the most efficient head end configuration is TDM/TDMA, as the number of central site modems is greatly reduced.

Another advantage of multipoint operation is that users can dynamically share the cable capacity on a demand basis. Time Division Multiple Access with demand assignment is one way in which this efficient use of central hardware and cable capacity may be effected. Other alternatives such as Random Access Protocols (e.g., CSMA-CD), although applicable to intra-building or campus networks, are not applicable for the situation under consideration. This is primarily because of the larger propagation delay and the fact that the traffic presented to the system can be expected to be non-bursty in many cases (e.g. facsimile and digitized video).

Time Division Multiple Access coupled with statistical multiplexing provides a very cost competitive method for concentrating many low rate bursty users. This networking technique can have widespread application in residential interactive services and can be quite easily integrated into a point-to-multipoint business network.

One innovative system which has been designed especially for high performance digital data transmission over coaxial cables is called Cable Access Packet Communications, or CAPAC-2. Each CAPAC-2 subscriber is provided with several data ports. These may be either high-speed (56 kbps) ports or low-speed (50 to 9600 bps) ports. The number of ports per subscriber may be increased easily, as required. Logical interconnectivity among subscribers is provided through connections at a central facility which serves a city-wide area. Network assignments are fixed but can be changed manually at the central facility.

In a typical installation, a frequency translator at the CATV head end facility relays 1.544 Mbps data carriers between the CAPAC-2 central transceiver and the various cable subscribers. It is desirable for the central facility and the CPS satellite earth station to be collocated. If this is not possible, a bidirectional digital link would be installed to connect these two facilities. Two cable channels, each carrying two data carriers, would be required to operate over a single-cable bidirectional system, assuming that suitable amplifiers have been installed to support two-way operation.

The CAPAC-2 system sends Time-Division Multiplexed (TDM) digital data downstream from the head end to the subscribers. Each subscriber station receives the entire data stream at 1.544 Mbps, which is then processed to identify the portion of the data which is addressed to that subscriber. This data is captured in buffer memory and subsequently transferred to the subscriber's data terminal equipments at the appropriate data port rates.

The subscriber unit continuously monitors the downstream data to decode frame timing information. At appropriate predetermined times, the subscriber unit turns on its carrier and begins transmitting data upstream. After a certain predetermined time interval, data transmission is stopped and the carrier is

turned off in order to enable other subscribers to transmit their data. In this manner, a single central facility is shared among the subscribers in a city area.

A typical frame structure for the fixed assigned TDM/TDMA transmissions is shown in Figure 3.1-27. Note that two "channel port" or user data slots are provided per subscriber. These data slots vary in length, depending on the port rates selected. Each pair of 1.544 Mbps carriers provides the capability for up to about 24 high-speed and 24 low-speed ports to be served. Expansion to accommodate additional subscribers is readily accomplished by adding TDM/TDMA carriers.

The operation of the CAPAC-2 system may be illustrated with the aid of Figure 3.1-28. The CATV central facility transmits, in a TDM fashion, to the head end in the low frequency band. The head end then acts as a frequency translator, causing the TDM data stream to be distributed to all subscribers in the high frequency band. Cable subscribers transmit in distinct time slots, as defined by the TDMA frame, to the head end in the low band. The head translates the TDMA carriers to high band for transmission to the central facility. This method requires two 6 MHz video channels (one for high band and one for low band). Two carriers are inserted in each direction.

The characteristics of the cable system equipment are shown in Table 3.1-12. The CAPAC-2 central Transceiver is shown in Figure 3.1-29. Ports are provided which correspond to the ports used at the subscriber stations (two ports at each subscriber). The transceiver modem interfaces directly to the CATV system at the appropriate RF frequencies.

The Subscriber Cable Transceiver is shown in Figure 3.1-30. Two full-duplex data ports are shown--one high-speed and one low-speed. More ports can be added if necessary. The transceiver interfaces directly to the CATV system at the appropriate RF channel, using either one cable or two as required by the particular CATV system.

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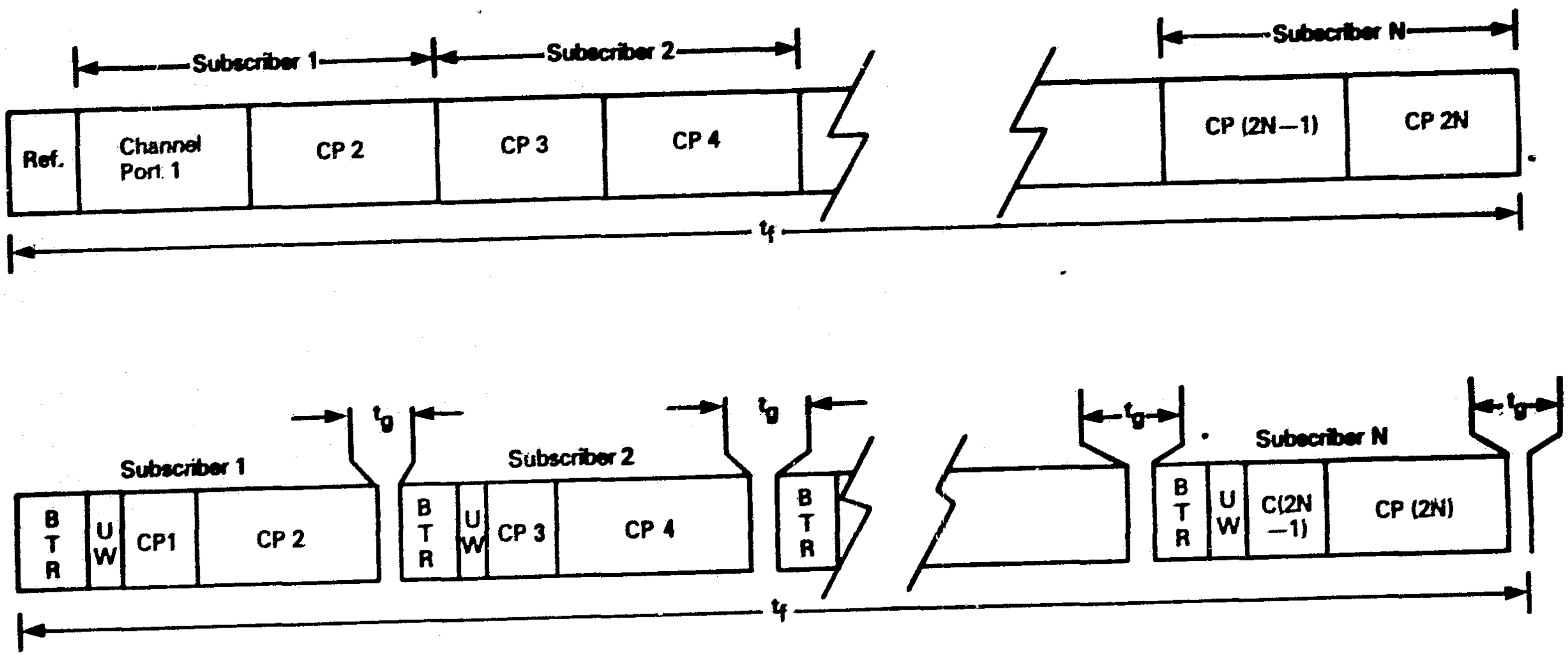

Ref.: Reference Unique Word
BTR: Bit-Timing Recovery (40 Symbols, 80 Bits)
UW: Unique Word (10 Symbols, 20 Bits)
t_g: Guard Time (10 Symbols, 20 Bits)
t_f: Frame Time (60 or 120 msec, Variable)
TDMA Overhead = $(BTR + UW + t_g) = (80 + 20 + 20)$ = 120 Bits Per Burst
= 120 Bits per Frame per Subscriber

Figure 3.1-27. Cable TDM/TDMA Frame Structure

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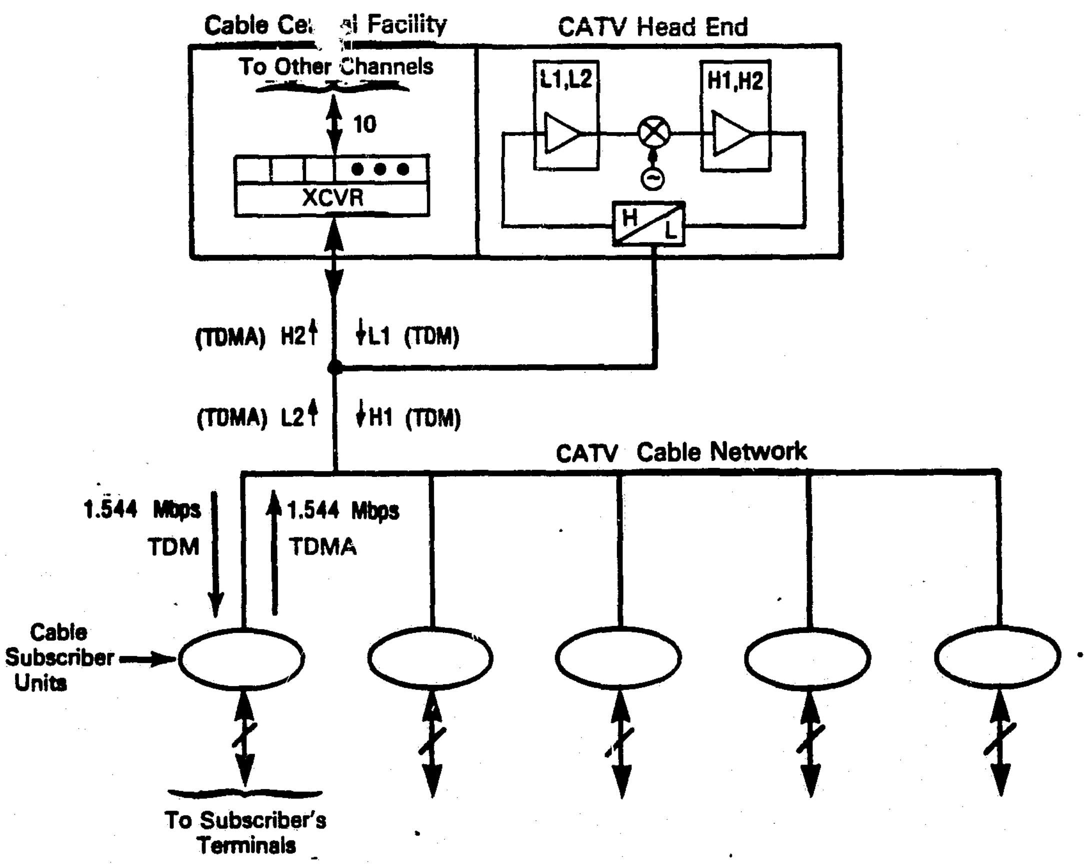

Figure 3.1-28. CAPAC-2 System Operation

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Table 3.1-12. CAPAC-2 System Characteristics

Frequency Band:	5 - 300 MHz CATV band
Channel Spacing:	Two carriers per 6 MHz TV channel compatible with CATV channeling
Modulation Rate:	1.544 Mbps
Type of Modulation:	Four-level FSK
Transmission Mode:	Central-to-subscriber TDM Subscriber-to-central TDMA
Frame Time:	60 or 120 ms. - factory programmable
Frame Assignment:	Fixed - field programmable
BER Performance:	1 x 10^{-8} in a typical CATV system
Spurious Outputs (out of band):	-70 dBc or less

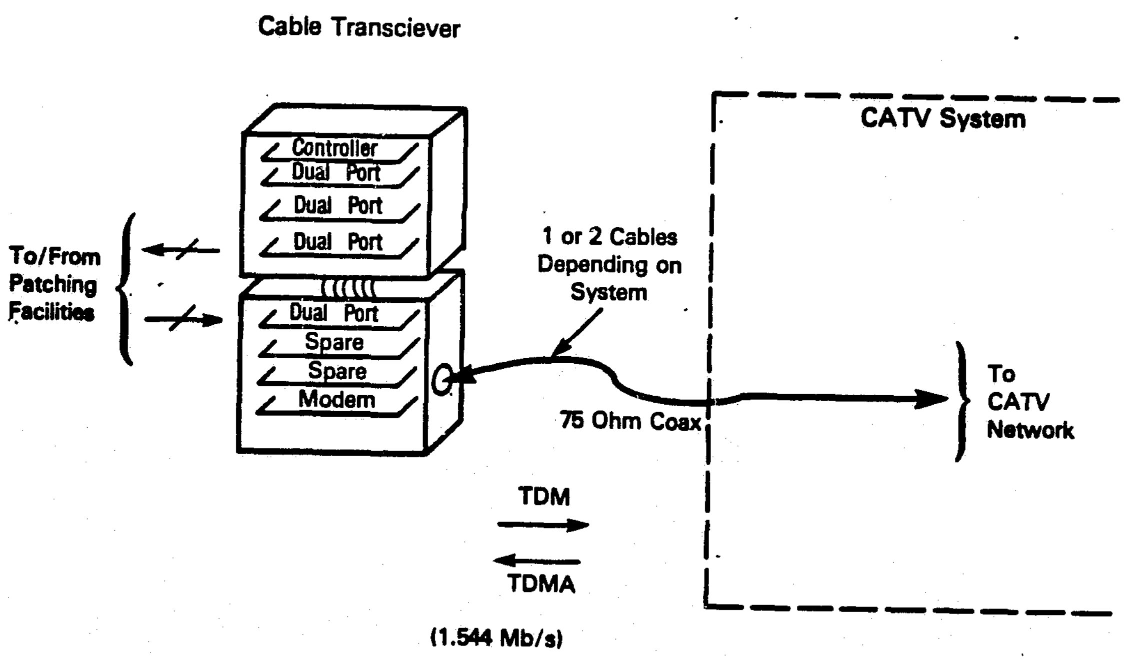

Figure 3.1-29. CAPAC-2 Central Transceiver

Table 3.1-13. CAPAC-2 Subscriber Unit Specifications

• 56 kbps Data Port Interface	CCITT V.35, Synchronous
• Low-Speed Port Interface	EIA RS 232C, Synchronous or Asynchronous
• Low-Speed Port Rate Asynchronous Operation	15 discrete rates between 50 bps and 9600 bps selectable by user option Parity: even, odd, or none Word length: 5, 6, 7, or 8
• Modem Modulation	Four-level FSK
Data Rate	1.544 Mbps
Clock	Internal crystal controlled (or external)
Clock Recovery	Internal crystal controlled
Transmit Frequency TDMA	5 - 30 MHz
Receive Frequency TDM	54 - 300
Transmit Level	+11 dBm (+ 60 dBmV)
Impedance	75 ohms
Receive Carrier Level	-35 to -55 dBm
Bit Error Rate Performance	1×10^{-8}
• TDM/TDMA Controller	1.544 Mbps
• Operating Temperature	0^{o} to $+40^{o}$C

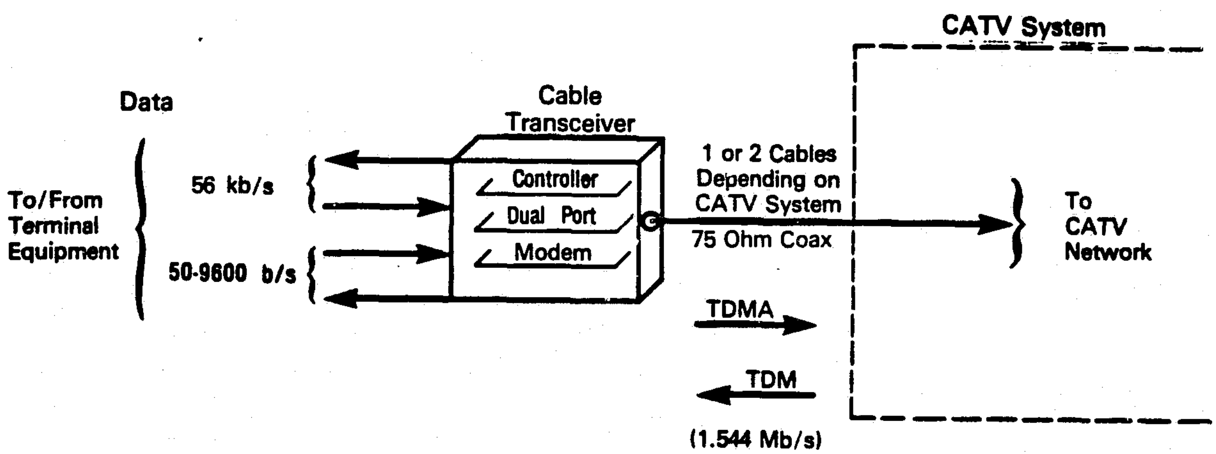

Figure 3.1-30. CAPAC-2 Subscriber Transceiver

The subscriber unit contains one or more "dual port" cards, each of which has a 56 kbps data port and a low-speed data port. A four-level FSK modem, a TDM/TDMA controller, and a power supply are also contained in the subscriber unit enclosure. Data demodulation is accomplished by means of a limiter/discriminator. TDM transmission to the subscribers typically takes place in the 54 to 300 MHz band used for video distribution. The return TDMA link from subscribers in a typical CATV system utilizes the 5 to 30 MHz band. The modem operates at a 1.544 Mbps rate. The specifications of the CAPAC-2 subscriber unit are given in Table 3.1-13.

The central terminal is functionally similar to the subscriber unit, except that it has the capability to receive burst TDMA transmissions. A block diagram of the Central station configuration is shown in Figure 3.1-31.

Point-to-Point and Point-to-Multipoint Fiber Optics: Fiber optics technology has recently been developed to the point where we may expect its rapid and widespread introduction into communications systems during the next decade. Optical fiber offers many performance features which include high bandwidth in a small diameter cable, freedom from electromagnetic interference, electrical isolation, freedom from spurious emanation, and high reliability.

A number of field trials of digital optical fiber transmission systems are in operation in several countries, such as the U.S., Japan, the U.K., and West Germany among others, at bit rates from 1.544 Mbps to 140 Mbps per fiber (or per source). Typically these systems employ semiconductor laser sources, avalanche photodiode detectors, and multimode graded index fibers. Most of these operate in the wavelength range of 0.82 - 0.84 nm. More recently, there have been introduced several systems based upon single-mode fibers, and operating in the wavelength range above 1 micron where fiber cable losses lie in the range of 1-2 dB/km (as against 5-7 dB/km for earlier optical cables.) Future systems may eventually operate at bit rates of several Gbps.

A fiber optics transmission link includes transmitters, fiber cable, receivers and regenerative repeaters.

In addition, connectors, splices and couplers are needed to assemble a transmission system.

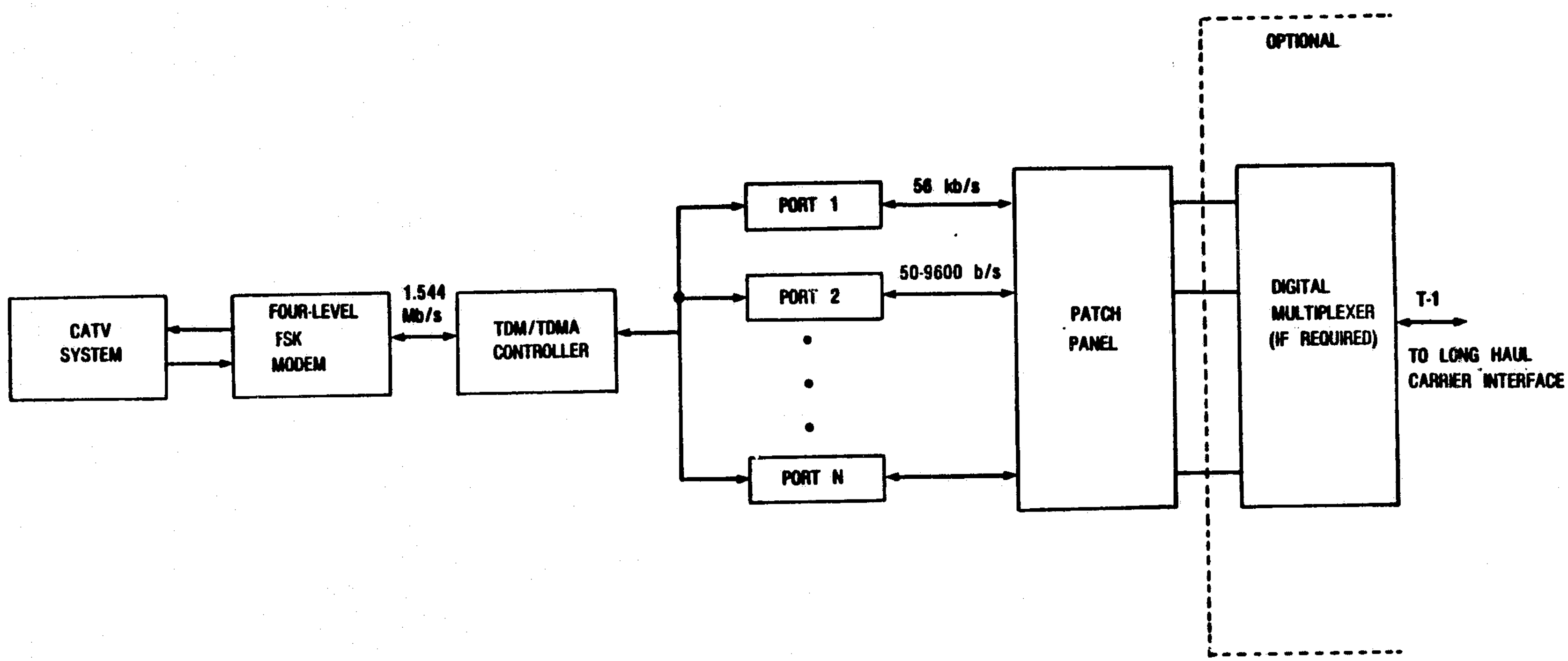

Figure 3.1-31. Block Diagram CAPAC-2 Central Unit

A key feature of the optical fiber is that its attenuation does not depend upon modulation bandwidth, as is the case for coaxial cable. A buffered optical fiber, which may be only 0.015 inches in diameter, has an attenuation that may be as little as a few dB/km and is constant over the modulation bandwidth. By contrast, the attenuation of a coaxial cable increases roughly as the square root of frequency so that to achieve low attenuation at higher bandwidths, a large diameter cable is needed. Figure 3.1-32 shows a comparison of attenuation characteristics for various cables and for optical fiber. Fiber dispersion can limit the fiber bandwidth, but special fiber construction techniques reduce this problem. The three types of fibers currently used are single mode step index fiber, multimode step index fiber, and multimode graded index fiber.

The fiber is a dielectric waveguide consisting of a light propagating core with a given index of refraction and a surrounding cladding region with a different index of refraction. This difference in the index of refraction determines the acceptance angle over which the fiber will accept and propagate light. Two sources of dispersion limit the fibers data rate or bandwidth capacity. These dispersion sources are modal dispersion and material dispersion. Modal dispersion results from group delay that occurs in multimode fiber due to the unequal group delay of the various propagating modes. Material dispersion results from the nonlinear variation of the fibers index of refraction as a function of wavelength and occurs in all types of fiber. Cables are made by combining one or more fibers into protective enclosures.

Optical transmitters contain a driver and a light source. Two types of light sources are currently used: light emitting diodes (LED) and injection lasers. The linewidth of the LED is about 35 nanometers, compared with a linewidth of only 2 nanometers of the injection lasers. Large linewidths limit the transmission system data rate due to material dispersion. For this reason the injection laser is more suitable for systems which require large bandwidths and transmission distances. However, the injection laser is currently less reliable and more expensive than the LED.

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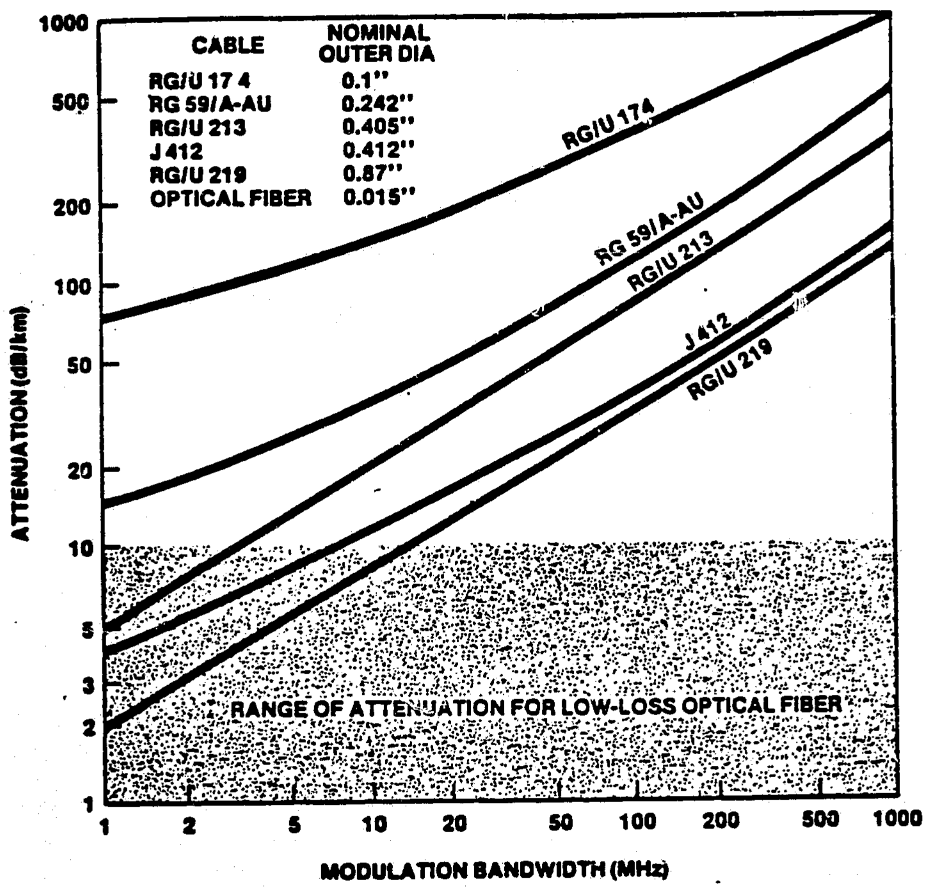

Figure 3.1-32. Comparison of Attenuation Characteristics Of Cables and Optical Fiber

Solid state photo diodes are used for reception of fiber optic communications. PIN photo diodes and avalanche photo diodes (APD) may be used. The APD diode has greater sensitivity and is less limited by thermal noise than the PIN diode, and it is somewhat more expensive.

Transmission over fiber optics have generally been digital due to the greater susceptibility of analog signals to non-linear characteristics of fiber optic modulators. The driver amplitude modulates the light source, and the receiver translates the light level variations into electrical signals. A regenerator is used to reconstitute a clean digital bit stream. Analog-to-digital and digital-to-analog converters can be used where analog signals have to be transmitted.

One main advantage of fiber optics systems is their ability to carry high data transmission rates. As a result, fiber optics systems have become economical at higher transmission rates. For applications with relatively low data transmission rates, the fiber optics systems may not become economical for some time.

Anticipated fiber optic component costs for the late 1980's expressed in 1980 dollars are shown in Table 3.1-14. These costs assume large quantities.

Table 3.1-14. Fiber Optics Component Costs (1982 Dollars)

Item	Unit Cost
Bus Interface Unit	1,000
Modem (LED, APD)	1,000
Tee Coupler	500
Repeater	2,500
Repeater Power Supply	2,500
Repeater Housing	2,500
Cable, Local Distribution or Trunk	1.50*
Cable Installation	5.00**

* Per meter for 2 fibers

** Per meter, average

The use of fiber optics is most attractive for local or short distance distribution of data. For example, a building or complex of buildings could be interconnected by fiber optics. The high transmission capacity of fibers makes costly rewiring unnecessary. On the other hand, unless right-of-way already exists or is relatively easy to acquire, the feasibility of long-haul distribution of data is not so attractive. The costs of installation amounts to $5 per meter. When compared to installation within a building, the cost for long-haul applications is significantly higher.

The state of the technology today is such that it is still uneconomical to install optical fiber cables in the local loop plant in a one-for-one substitution for the wires in paired cable. The time is rapidly approaching when optical fiber cable and some combination of T3, T2, T1C and T1 optical digital carrier could be economically employed in loops, however. Special custom routes may be as economically implemented with optical fiber as with coaxial cable, since the cost of the medium itself is not significant compared to pole costs, trench costs, and labor costs for installation.

Point-to-point fiber optic links are inherently wasteful of bandwidth, except for heavy (T3) trunking applications typical of today's installations. The fiber optic medium is by nature point-to-point, but may be used in a point-to-multipoint fashion using drop and insert devices.

One product on the market today, made by ITT, provides a point-to-point T2 link. The cost is approximately $5,000 per end, excluding fiber and installation.

The other main supplier of sub-T3 equipment is DCC. DCC's LTR system has 10 T1 capacity per fiber. Drop-and-insert hardware has the capability of accessing individual voice channels within the T1 but the most economical option is to drop and insert T1 channels and allow the user devices to demux as required. LTR may be configured as point-to-point. The equipment cost is $15,000 per end, plus $1,700 per 2 T1 drops.

Depending on the subscriber distribution, either the ITT point-to-point or DCC point-to-multipoint equipment may be most economical.

For example (refer to Figure 3.1-33), suppose there is initially a pool of users at A having an aggregate T1 requirement, and at a distance of L_1 km from the central. Clearly, as there is only one location that is to be served, it is cheaper to install the ITT equipment. The cost of doing this is \$10,000 + \$4,500 L_1.

Next, another pool of users needs to be served at location B, as shown in Figure 3.1-33. There are two choices:

1. Another independent ITT link can be installed from the central to B. The cost of doing this is \$10,000 + \$4,500 L_2.
2. The old ITT link to A can be removed and an LTR system installed between the central, A, and B. Noting that the fiber from the central to A already exists, the cost of doing this is \$15,000 x 3 + 1,700 x 3 + \$4,500 L_3.

Thus, the upgrade to LTR should be made when

$$50{,}100 + 4{,}500\ L_3 < 10{,}000 + 4{,}500\ L_2$$

i.e. when $L_3 < L_2 - 8.9$ km.

Analog Video Links

The projected traffic captured by the 30/20 GHz network includes a great deal of video traffic. Due to the potential for an advanced space segment concept requiring all-digital transmission, all video traffic has been expressed in equivalent peak hour bits per second. It may be wise to include the potential for analog video transmission in the ground networking concept. This allows the video codec to be placed at the CPS station and shared among several users, who can employ conventional TV receivers and transmitters, i.e., analog units.

Two well established technologies exist in the previously identified ground networking equipment to provide analog video transmission. Point-to-point analog microwave units are widely used for video transmission and coaxial cable hardware was expressly designed for the transmission of analog video signals. Data or digitized voice can be carried in the same architecture through the use of the audio sub-carrier band or Frequency Division multiplexing. Figure 3.1-34 is a block diagram of such a configuration.

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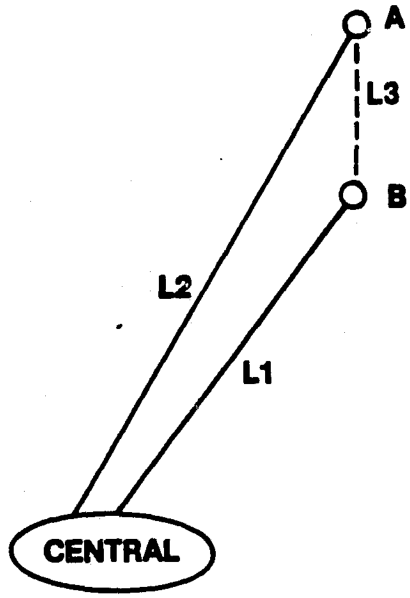

Figure 3.1-33. Fiber Optic Example

CPS Station - Central Node Link

It may not always be possible to calcolate the intercity gateway CPS earth station and the central node of the local distribution system. This may be due to:

1. Frequency interference problems, which may necessitate the location of the earth station away from the city which the local distribution system serves.

2. The location of the earth station, even when in the city, may not be the best possible location for the central node of the local distribution system. This may be due to line of sight, area coverage, or traffic distribution considerations.

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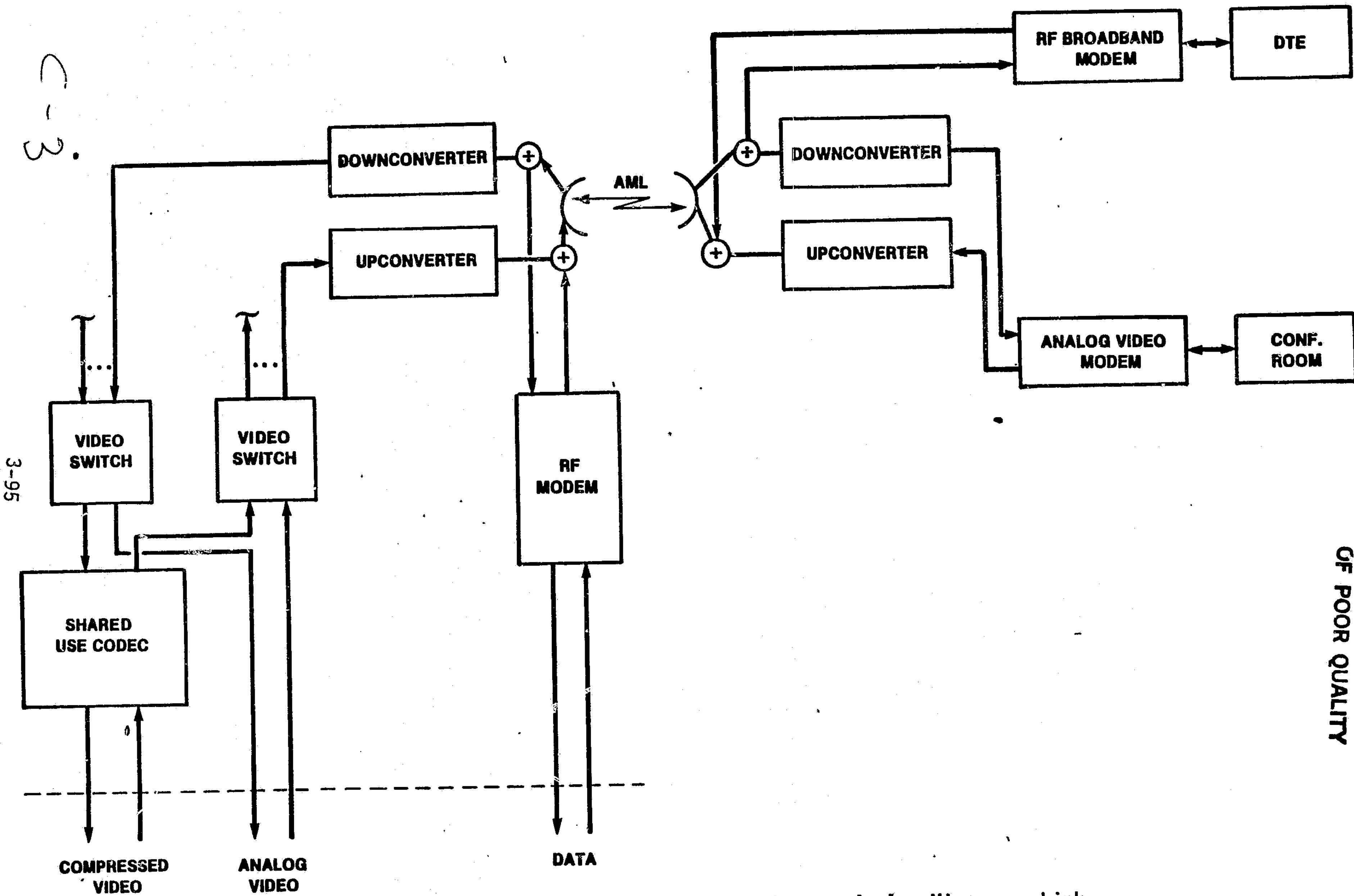

Figure 3.1-34. Video and Data Carried on an Analog Microwave Link

Assumptions

1. The link is to be a high data rate link, e.g., at least a T1.
2. It must be redundant.
3. Off-the-shelf equipment is to be used to construct the link.
4. The local distribution system has a single central node.
5. The local switch can accept both port and multiplexed interfaces and can be located at either the earth station or the central node. If required, it can put out a multiplexed stream.

Archetictures: The simplest configuration is for a single earth station.

Technology alternatives for the entrance link include point-to-point microwave radio, coax cable, fiber optic cable and other carrier links, e.g., DDS.

The choice of an appropriate technology depends very much on the local availability, frequency congestion, and other issues. It should be noted that all the media listed above can provide high data rate links with virtually off the shelf equipment.

Another alternative is to consider a hybrid approach assuming dual redundant links. One can be a microwave link and the other can be a CATV link, for example.

It is quite likely that the earth station-to-central node link is not capable of being provided by a single hop. Then, functional repeaters will have to be used. The different hops in the link may consist of different media, e.g., the first hop may be a cable, followed by a microwave hop. This enhances the argument for using standardized rates and formats on the entrance link.

High rate point-to-point radios are available off the shelf with automatic switchover capabilities, e.g., the Farinon DM 18 Radio.

If the local distribution system is constructed using point-to-point links, then multiple earth stations can be treated independently of one another.

Feasible Ground Networking Concepts

Several combinations of media and topology have been identified as viable for accessing a CPS Station. Table 3.1-15 lists the various impacts of users' requirements and distribution on the feasibility of each concept. Table 3.1-16 identifies several important criteria surrounding each networking architecture.

Hybrid Systems

It should be clear from the foregoing that no single candidate transmission medium will suffice in every situation. This is because each medium has certain inherent drawbacks. For example, atmospheric optical systems are effective only for very short distances; point-to-point microwave systems have far greater range, but require frequency clearance for FCC licensing, which may not be possible in dense urban areas.

A hybrid system approach offers the designer the flexibility to take advantage of the capabilities of each medium in the situation for which it is best suited. On the surface, then, a hybrid system may appear to be the "best" system, in general. This conclusion, however, overlooks some of the more practical aspects of installing, operating, and maintaining a communications network. For example, standardization of components is a technique which is commonly used to reduce operating costs. The use of a relatively small number of standardized system building blocks eases the training requirements for network personnel, results in administrative simplification, facilitates spare parts and inventory stock procedures, and permits savings in parts procurement because of quantity discounting.

Thus it is clear that the selection of a system architecture represents a tradeoff among cost, technical performance factors and operational requirements. One approach to this selection is to rank the various candidate transmission media to indicate an order of preference in satisfying the requirements of each network path. This ranking is normally specified in order of some normalized cost, assuming that schedule, licensing, and reliability requirements have been met by all candidates under consideration.

Table 3.1-15. Characteristics of Candidate Ground Networking Options

TYPE	APPLICABLE USER CLASSES	APPLICABLE TRAFFIC CLASSES	APPLICABLE USER ENVIRONMENTS	APPLICABLE USER DENSITY
POINT-TO-POINT DIGITAL MICROWAVE RADIO (STAR)	Large Installations Clusters of Low Capacity Subscribers	PRECONCENTRATED (T1) Relatively Constant Traffic Load in the Peak Hour Compressed Video	LOS Required Adequate Spectrum Required	Pockets of High
POINT-TO-POINT DIGITAL COAXIAL CABLE MODEM MODEM (STAR)	Large Installation Clusters of Low Capacity Subscribers	Preconcentrated (T1) Dedicated Networks Compressed Video	Areas where business is served with CATV Areas where rights of way may be obtained	Linear or other high density area corresponding to rights of way
POINT-TO-POINT FIBER OPTIC CABLE (STAR)	Large Installations Clusters of Low Capacity Subscribers	Preconcentrated (T1) Compressed Video Allowance for Analog video	Areas Where Rights of way may be obtained	Linear or other High Density areas Corresponding to Rights of Way
TELCO DDS	All	All but Video	Cities serviced by DDS	N/A

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Table 3.1-15. Characteristics of Candidate Ground Networking Options (Cont.)

TYPE	APPLICABLE USER CLASSES	APPLICABLE TRAFFIC CLASSES	APPLICABLE USER ENVIRONMENTS	APPLICABLE USER DENSITY
POINT-TO-MULTIPOINT MICROWAVE RADIO (DTS)	Low Capacity Subscribers (1 or 2 Circuits) Non-Multiplexed	Bursty Stream Data (low duty cycle terminals)	Wide Range of LOS from Central location Area where DTS bands are not saturated	Widespread Uniform Distribution
POINT-TO-MULTIPOINT COAXIAL CABLE MODEMS	Low Capacity Subscribers Non-Multiplexed	Bursty Stream Data (low duty cycle terminals)	Areas served by CATV Areas with heavy Microwave Congestion	Uniform distribution along rights of way
POINT-TO-MULTIPOINT FIBER OPTIC SYSTEM	Preconcentrated (T1) Low capacity Subscribers	All but Video	Areas with accessable rights of way	Linear
POINT-TO-POINT DIGITAL MICROWAVE RADIO (RING)	Large Installations Clusters of Low Capacity Subscribers	Preconcentrated T1 Compressed Video	LOS Required Connecting primary to deversity site	Clusters of high density Linear
POINT-T POINT COAXIAL CABLE MODEMS (RING)	Large Installations Clusters of Low Capacity Subscribers	Preconcentrated (T1) Provision for analog Video	CATV or other rights of way available connecting primary and diversity	Clusters of high density Linear

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Table 3.1-16. Significant Characteristics of the Networking Options

CRITERION / TECHNOLOGY	POINT-TO-POINT DIGITAL RADIOS	POINT-TO-MULTIPOINT RADIOS	POINT-TO-POINT CABLE	POINT-TO-MULTIPOINT CABLE	POINT-TO-POINT-FIBER	POINT-TO-MULTIPOINT FIBER	TELCO WIRE PAIRS	DDS
INITIATION DELAY (MONTHS)	1-2 For 23 GHz 3-6 Others	3-6 For Central 1-2 For Subs.	12 - 36 Including Installation 2 - 3 Not Including Installation				3-12	6-24
SERVICE AVAILABILITY	POSSIBLE IN ALL U.S. CITIES		2-Way CATV SYSTEM UNDERWAY IN MOST LARGER U.S. CITIES		FIBER NOT INSTALLED IN ANY U.S. CITY		Most U.S. CITIES	95 U.S. CITIES
TYPICAL BER	10^{-5} for 23 GHz 10^{-6}	10^{-8}	10^{-8}		10^{-9}	10^{-9}	10^{-5}	99.5% ERROR FREE SECS (SPEC)
DATA RATES	Up to T2	LESS THAN T1	UP to T2	LESS THAN T1	Multiple T1s and T3	Multiple T1s	Up to 56 kbps	Up to 56 kbps
DEMAND ASSIGNMENT	NO	YES	NO	YES	NO	YES	NO	NO
ADDITION OF SUBSCRIBER	NEW LINK	NEW SUBS UNIT	NEW LINK	NEW SUBS UNIT	NEW LINK	NEW TAP, REPEATER & SUBS UNIT	NEW LINK	NEW LINK
REDUNDANCY	1:1 per Link	1:1 Subscriber 1:N CENTRAL	1:1 per Link	1:1 Subscriber 1:N Central	1:1 per Link	1:1 Subscriber 1:N CENTRAL	1:1	1:1

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Table 3.1-16. Significant Characteristics of the Networking Options (Cont.)

TECHNOLOGY / CRITERION	POINT-TO-POINT DIGITAL RADIOS	POINT-TO MULTIPOINT RADIOS	POINT-TO-POINT CABLE	POINT-TO-MULTIPOINT CABLE	POINT-TO-POINT-FIBER	POINT-TO-MULTIPOINT FIBER	TELCO WIRE PAIRS	DDS
REGULATIONS	FCC Type Acceptance Freq. Coord.	FCC type Acceptance Blanket lic.	State PUC	State PUC	No Precedent	No Precedent	TARIFFED	TAR-IFFED
TYPICAL COVERAGE RANGE	2 mi (23GHz) 5 mi (18GHz)	6 mi	15 mi	15 mi	6 mi	22 mi	N/A	N/A
FREQ. REUSE	Up to 100 Subs per Central, Central Freqs Different	Unlimited # of Subs, Freq Reuse Plan	Possible with trap filters		N/A	N/A	N/A	N/A
MAJOR EQUIP SUPPLIERS	Farinon, Avantek, NEC, RACON, GE, MAC	LDD, Avantek, NEC	AMDAX, Cablebus, Catel, S/A	LDD, AMDAX	ITT, DCC	DCC	TELCO	AT&T
VALUE ADDED FEATURES	External MUX, Switch	Software Upgrades	External MUX, Swithch etc.	Software Upgrades	External	Internal	External	In-ternal
OVERALL NETWORK CONTROL	Not Always Available	Sophisticated	Not Always Available	Sophis-ticated	Not Always Available	Sophis-ticated	NONE	NONE
FUTURE COST PROJECTIONS	PROBABLE DECREASES WITH QUANTITY PRODUCTION AND VLSI IMPLEMNTATION						YEARLY INCREASES ARE PROBABLE	
PORT MULTI-PLEXING	External Addition with Extra Cost of MUX	Internal with Extra Cost of Port Card	External Addition with Extra cost of MUX	Internal with Extra cost of Port Card	External	Internal	External	Ex-ternal

A network architecture may then be selected, based on the ordered choices for the various links. The least-cost candidate for each link would not be automatically selected, however. Instead, second or third choices might be selected in order to achieve a degree of link-to-link uniformity. The basis for this selection is qualitative, rather than quantitative, and requires a degree of practical experience.

It naturally simplifies local distribution network design if the various transmission media which constitute the network terminate in a common location. This is not always practical, however. For example, the equipment associated with a RAPAC central node should ideally be located atop a tall building, with clear lines of sight to surrounding buildings. A CAPAC-2 central node, on the other hand, should ideally be collocated with a CATV head end, shown in Figure 3.1-35. Thus certain compromises will be required in the selection of central node locations, and judgemental factors again come into play.

These judgmental factors are also important for estimating the level of customer acceptance of the various candidate means of regional distribution. For example, some customers may have an inherent distrust for buried cable systems of any kind, stemming from experiences of service outages encountered during roadbuilding or other construction.

3.1.3 IMPLEMENTATION OF SPACE DIVERSITY

A solution to the availability problems introduced by the severe rain fading at 30/20 GHz is provided by two or more earth station locations for each CPS subscriber base. Due to the localized nature of heavy rain showers, two earth stations located 10 to 15 km apart will have a very low probability of simultaneously experiencing a disrupting rain fade. The key component in such an availability enhancement configuration is the interconnecting link which provides the switchover capability. The distances involved correspond to the typical geographic extent of most ground networking media, therefore such equipment should serve as logical candidates to perform the interconnection. Additionally, if the the topology of the user base and environment makes it possible for all subscribers to be located between the two earth stations, the ground network and the space diversity interconnection could share common equipment. This strategy for equipment sharing becomes particularly attractive when guided media architectures are considered.

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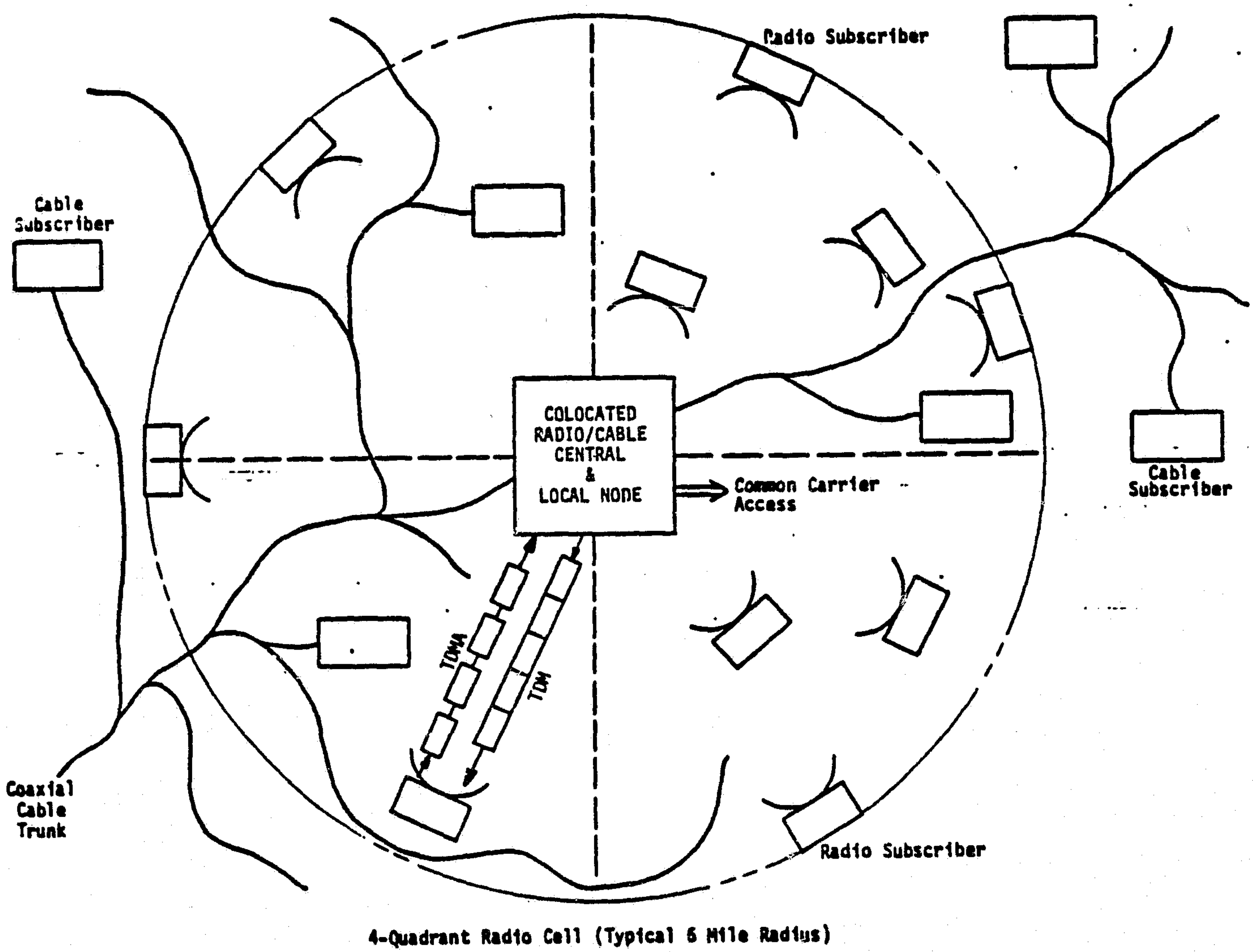

Figure 3.1-35. Hybrid Local Distribution Network

Additional Requirements Imposed by the Use of Space Diversity

The majority of the processing and hardware required to implement space diversity will be incorporated into the earth station baseband equipment. Specific additional components include logic to determine when to initiate switchover, hardware to perform the switchover, and fixed delay compensation buffering to accommodate the propagation path length of the interconnecting link.

The theory behind space diversity operation is that each CPS station can monitor the link performance, predict when a disruptive fade will occur, and shunt the data transmission function to a diversity site. The key to successful implementation of this procedure is to ensure that a hitless switchover can take place. This means that data continuity is preserved so that no users become aware that the switchover has taken place. Figure 3.1-36 is a top level block diagram of one possible space diversity configuration. The site equipped with the baseband and user interface is the primary site. The other site in this configuration contains neither baseband equipment nor user interface, and is called the diversity site. Additional terms of importance are active site, the station transmitting user data, and standby site, the station that is inactive.

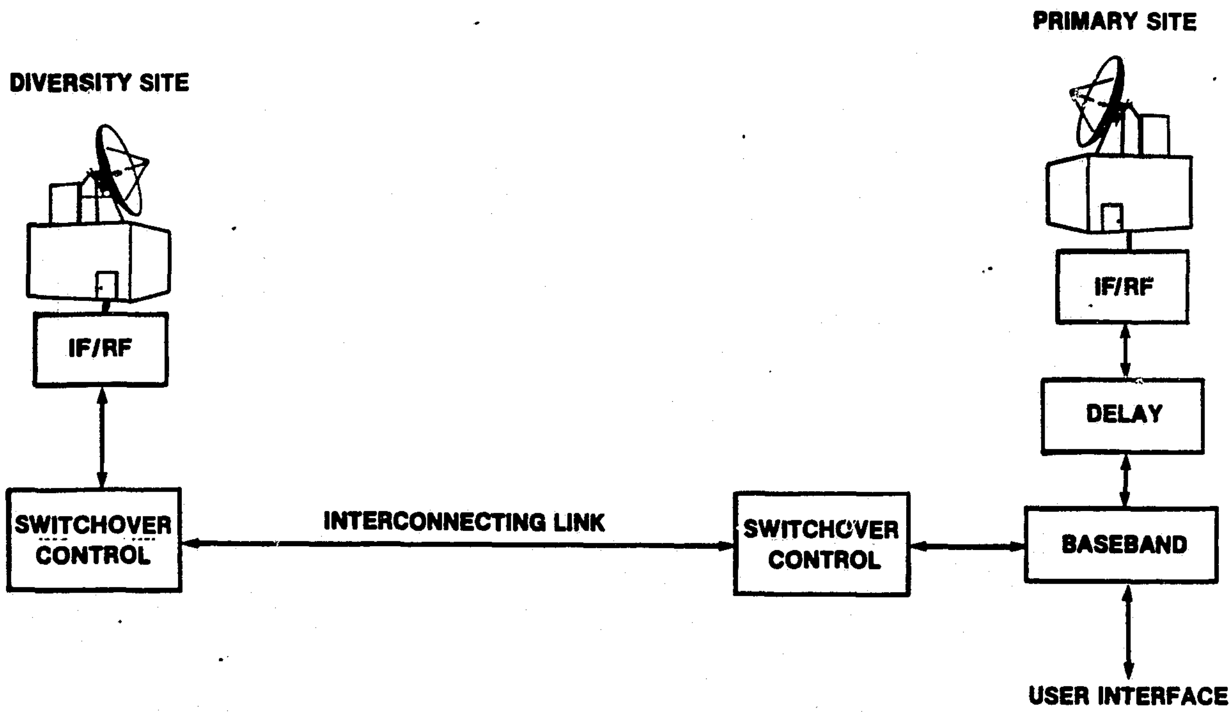

Figure 3.1-36. Top Level Space Diversity Configuration

Hitless switchover requires that the IF/RF Subsystem of both sites are receiving identical bit streams and/or video signals and that both sites are demodulating the downlink. Note that this requirement for hitless switchover places a larger limitation on a system with an FDMA space segment than on a system with a TDMA space segment. This is due to the fact that in a TDMA system, the baseband output is a single digital stream, burst out once per frame, which is the aggregation of all local user traffic. Similarly, the baseband input from the space segment is also a single digital stream. However, any FDMA system would have a baseband output on the uplink side of several channels. Delay compensation for more than one channel will add to the cost of diversity operation. Additionally, the diversity interconnect must carry several channels of data and those channels must remain synchronized.

The interconnecting link may be operated in either a TDM or a FDMA mode. TDM operation requires a pair of multiplexers, while FDMA requires several modem pairs. In addition to the extra cost involved with operation of the diversity interconnect, there are also space segment considerations, such as keeping the standby station in the network, which seem to favor TDMA space segment operation in conjunction with space diversity to enhance availability.

Implications of Digital Microwave Radio Upon Space Diversity Operation

Given that the space diversity solution is proposed to reduce the outages caused by rain fading, use of digital radios subject to the same fading may not be advisable. Additionally, in the time frame proposed for the 30/20 GHz program, it is expected that a great deal of congestion will exist in the lower frequency bands which are less susceptable to rain attenuation. Point-to-point microwave radios which operate in the 18, 23, or 26 GHz range, at data rates which would be sufficient for a space diversity interconnect (T2 and above), would require repeater spacings of not more than 4 km. In order to perform as required, the availability of the interconnecting link must be very high, necessitating the use of redundant repeaters.

Potential Architectures for Implementing Space Diversity

There are several architectures which may be selected to implement the terrestrial interconnect required for space diversity operation. The least complicated would be a dedicated link using any of the point-to-point media described in the previous section. The specific implementation would depend

on the space segment and the throughput of the earth station configuration, but in any case would be quite straightforward.

A second architecture is called for when circumstances separate the ground network central node from the CPS earth station site. This could be due to line of sight limitations, frequency availabilities, CATV plant, location or a number of other external factors. Should this be the case, two dedicated point-to-point links are required, as shown in Figure 3.1-37.

Given certain use distributions, as previously described, the space diversity interconnecting media can also serve as the trunking backbone for the ground network. The primary CPS site would serve as the central site for the ground networking, and as one endpoint of the space diversity interconnecting link. Figure 3.1-38 is a functional diagram of this hybrid link concept, shown for the case of the coaxial cable transmission plant.

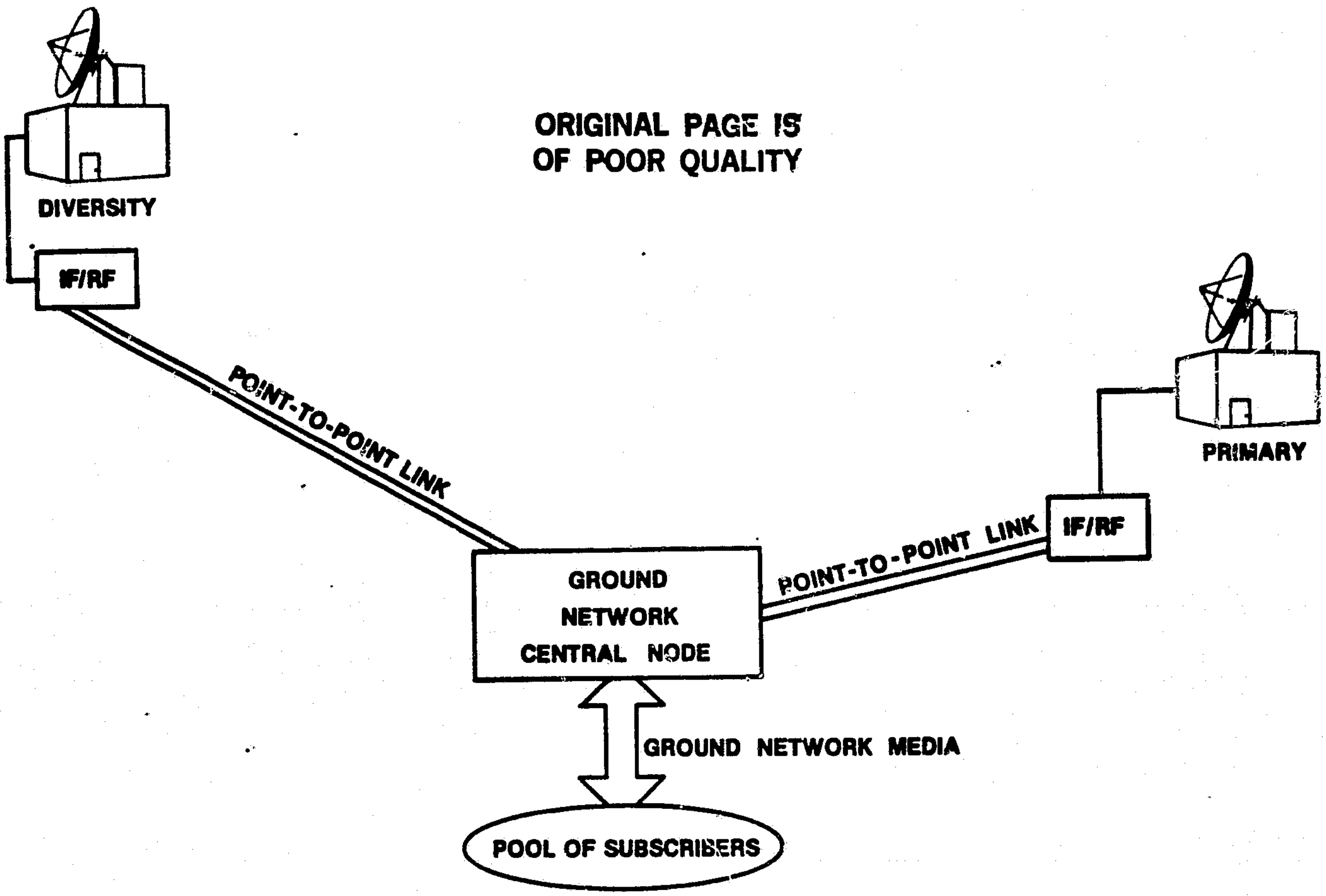

Figure 3.1-37. Space Diversity Implementation with
Ground Network Central Node Distinct from CPS Earth Station Site

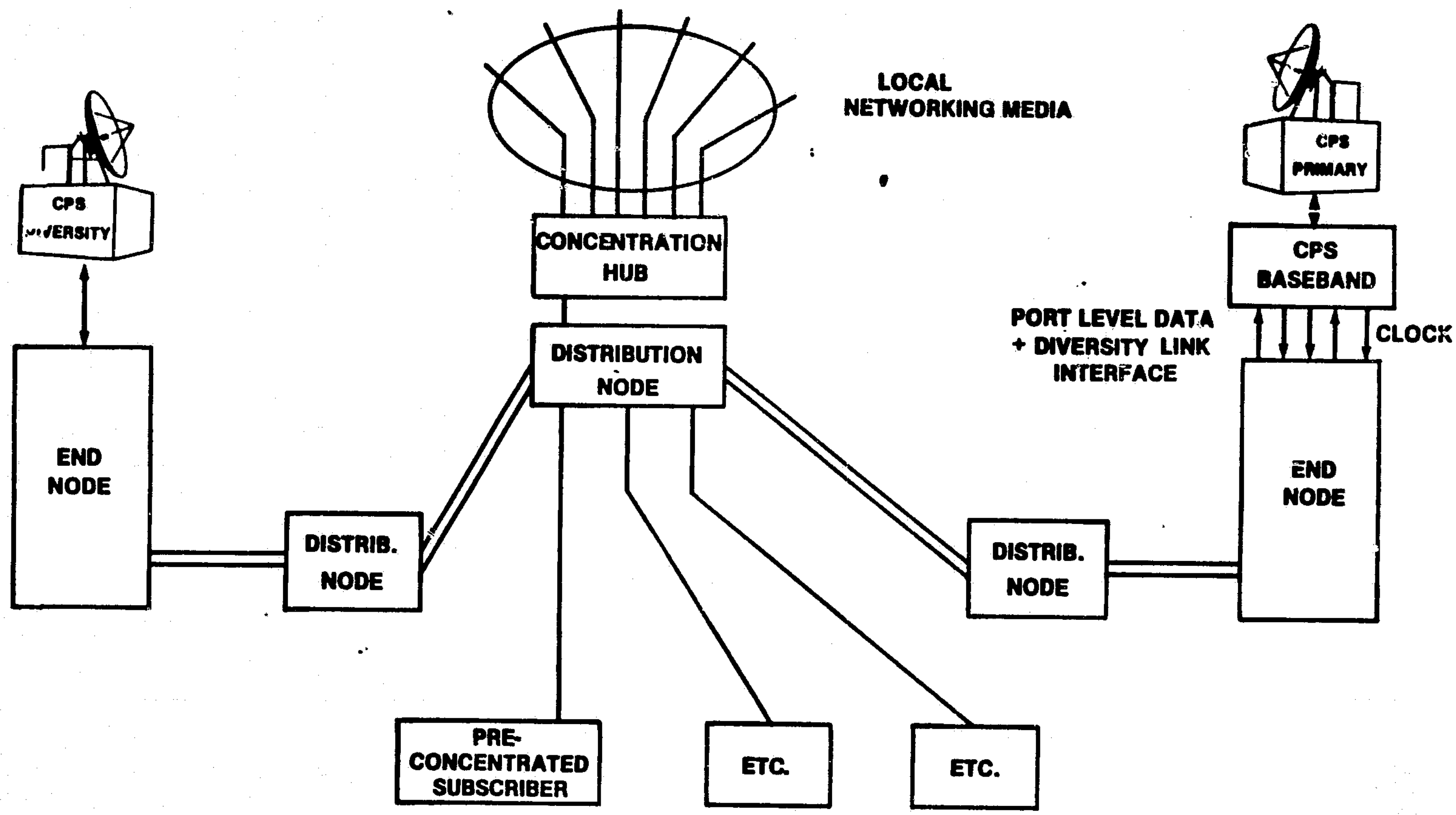

Figure 3.1-38. Architecture for Coaxial Cable Used As Ground Networking Medium and Space Diversity Interconnect

Implementation of Spatial Diversity Interconnecting Links Shared With The Ground Network

A highly workable solution is to provide at least two independent channels on the ground network trunk. One duplex channel, which would operate at the throughput rate of the CPS station, would be a point-to-point link to connect together the primary and diversity sites. The other channels will be used for CPS subscriber access and concentration. No matter which medium is chosen, the trunking backbone would need to be fully redundant and bi-directional.

As previously discussed, a digital microwave radio implementation of this hybrid approach would require very short link distances (less than 4 km) for sufficiently available operation. At this repeater spacing, the total number of repeaters (and hence concentration links, see Figure 3.1-39) would be quite large for a typical diversity site spacing and user cluster distribution. It is possible to envision a user distribution for which this hybrid network traverses far more path length mileage than the 10 to 15 km diversity site separation. This proliferation of repeaters, even redundant ones, has a profound effect on the overall system availability. This repeater spacing for digital microwave radios is limited by the losses and the local rain fall rates.

One way of increasing the path length between repeaters is to use guided media. Typical fiber optic systems have up to 6 km between repeaters. Coaxial cable has no need for repeaters in the true sense of the word. A repeater operates by detecting the received signal, reducing it to a baseband digital stream, and then remodulating. The principle behind this technique is to optimize each inter-repeater link. The communications link can be engineered so that the received signal has just enough carrier-to-noise ratio to be detected at a bit error rate within the specifications of the system. Due to this optimization, a simple amplification of the signal would not suffice. Were this attempted, the carrier-to-noise ratio at the next repeater would not be sufficient to achieve the required BER, that is, amplification only requires greater carrier-to-noise on each link.

A repeater configuration would be required for a fiber optic hybrid link. This is due to the limitation imposed by fiber optic tap technology, rather than excessive signal degradation. In fact, typical diversity site spacing could be easily spanned by an unrepeated fiber optic link. However, the

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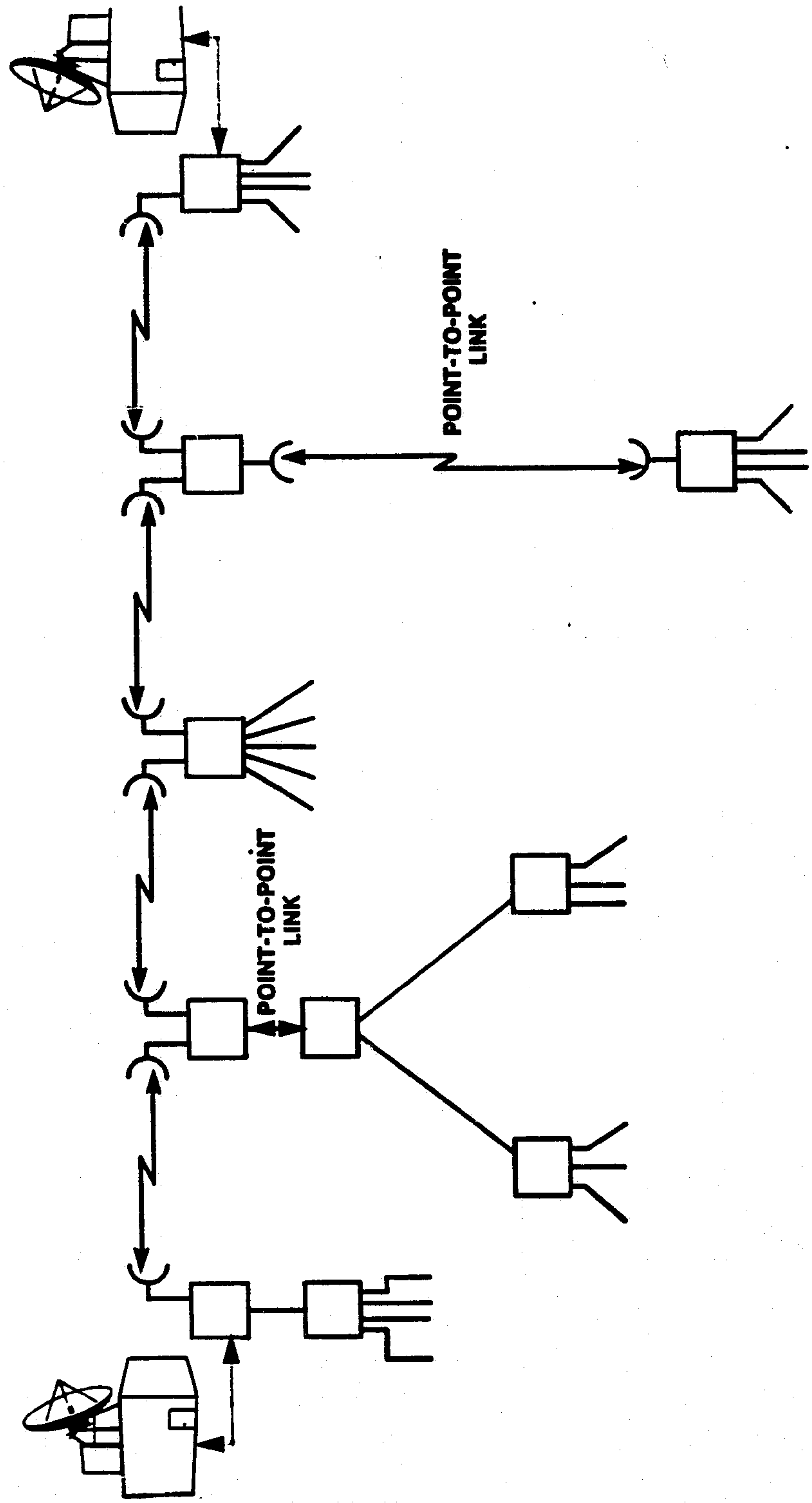

Figure 3.1-39. Linear Network with Hub Concentration to Provide Redundancy and Spatial Diversity.

hybrid architecture proposed here requires subscriber access to the link which so far can only be economically performed through a repeater tap.

Implementation of this hybrid architecture with guided media requires installation of a backbone, typical properties of which would include redundancy of all equipment, to ensure reliable communication in the event of any single equipment failure, and a shortest path routing which passes within 1 km of every subscriber location.

Local area networking technologies could be used to provide subscriber access to the backbone. The ground networking part of this hybrid architecture would be configured in one of the several ways identified in the previous section. The diversity interconnect should be configured as a point-to-point link. These links must be operated separately. For coaxial cable implementation, separate channels for the diversity link are required. For fiber optic implementation, each hop must also have a regenerative repeater for the diversity link. The fiber is shared in an FDM fashion. This technology is in development today and should be mature by the time of 30/20 GHz CPS implementation.

3.1.4 BUDGETARY COSTS ASSOCIATED WITH CPS GROUND NETWORKING

Of all the aspects of data communication, the provision of local loops is the area in which the greatest changes are taking place today. Examples which indicate the volatile nature of the digital local loop market include the opening of the 10.5 to 10.68 GHz band for Digital Termination Service, the number of firms gearing up to produce private digital microwave equipment at 23, 26 and 18 GHz and the continued development of freeze frame and compressed video codecs.

In spite of the indications of rapid growth in this market, there are a great many uncertainties surrounding the implementation and, particularly, the budgeting of such an implementation plan. All of these uncertain factors relate not to technology, but rather to regulation of carriers providing the service and also to the degree of competition in the industry. Additionally, in the time frame of the 30/20 GHz CPS station development, there are uncertainties surrounding the then mature local distribution environment. Such uncertainties incude typical number of competing carriers, expected degree of frequency crowding, penetration of existing ground networking

services and their potential application to the CPS ground network and position of AT&T in the market and their relative cost factors.

Application Scenarios

Based on the architectures outlined earlier in this report, several possible application scenarios are presented. In any real-world case, the optimal architectural configuration depends heavily on initial traffic requirements and the expected growth over time, geographical distribution of the traffic, existence of clear lines of sight, and availability of site locations for rooftop rental and availability of alternative media, such as cable optical fiber, etc., which varies on a city-by-city basis.

For the scenarios outlined in this section, no claim is made as to the depiction of any particular real-world city. Rather, the purpose of this section is to outline several sample configurations, in order to illustrate the architectural selection concepts developed earlier in this report.

Point-to-Multipoint Architecture Concentration Factors

One of the very attractive features which point-to-multipoint architectures offer is demand assignment in the communications medium itself. Furthermore, such architectures offer several levels of demand assignment, with the result that different concentration factors can be achieved for the same grade of service.

Table 3.1-17 shows the concentration factors that are realizable when no blockage is assumed in the carrier ports, i.e., the only blockage that can occur is in obtaining transmission bandwidth. Note that queuing functions have not been included; therefore, grade of service (i.e., blocking probability) is the parameter of interest in system architectural design.

DDS Tariffs

If DDS is to be used, two local loops would be required for a circuit between a subscriber location and an earth station; one from the subscriber to the central office and the other from the central office to the earth station. Assuming that each of these is two miles in length, the present costs of the circuit are given in Table 3.1-18. DDS tariffs are changed directly to the subscriber.

Table 3.1-17. RAPAC Concentration Factors

DATA RATE PER SUBSCRIBER (kbps)	0.1 ERLANG/SUBSCRIBER					0.2 ERLANG/SUBSCRIBER			
	NUMBER OF FIXED ASSIGNED CIRCUITS PER SECTOR	GRADE OF SERVICE 1:100		GRADE OF SERVICE 1:200		GRADE OF SERVICE 1:100		GRADE OF SERVICE 1:200	
		# OF CIRCUITS WITH DA	CONCEN-TRATION FACTOR	# OF CIRCUITS WITH DA	CONCEN-TRATION FACTOR	# OF CIRCUITS WITH DA	CONCEN-TRATION FACTOR	# OF CIRCUITS WITH DA	CONCEN-TRATION FACTOR
9.6	130	1,124	8.64	1,086	8.35	562	4.32	543	4.18
56	30	203	6.76	190	6.33	102	3.38	85	3.16
112	16	88	5.5	81	5.06	44	2.75	40	2.53
448	4	8	2	7	1.75	4	1	4	1

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Table 3.1-18. DDS Tariffs for Intracity Transmission

DATA RATE (kbps)	MONTHLY CHARGE	NON-RECURRING CHARGE
2.4	345.98	146.00
4.8	559.88	146.00
9.6	903.88	146.00
56	2537.40	220.00

CATV Tariffs

No CATV company, other than Manhattan Cable, currently is known to offer a data transmission service. The following figures are believed representative of current point-to-point tariffs within Manhattan.

56 kbps - $490/month
9.6 kpbs - $160/month

CATV tariffs are charged directly to the carrier.

Point-to-Multipoint Digital Microwave Radio Costs

The costs for the point-to-multipoint digital microwave radio, exhibited in Tables 3.1-19 and 3.1-20, have been derived from vendor surveys as to the capabilities and pricing of their standard networking products. The circuit costs associated with the RAPAC network are based on equipment costs obtained from Local Digital Distribution Company and the assumptions presented below.

General Assumptions

1. Cost of Money = 20% which with a 5 year amortization yields a conversion factor of 0.0265 on a monthly basis.
2. Annual Maintenance Costs = 15% of hardware costs.
3. Rent For Central Site = $150/month.

RAPC Equipment - Specific Costs Are:

1. Central = $117,500 plus port cards

2. Port Cards: RS- 449: $1,100
   RS- 232: 875

3. Subscriber = $11,500 including one RS- 232 port card

4. Shipping and Installation: Central $15,000
   Subscriber 4,000

5. FCC Permit Fees = $9,000

The analysis that follows is conducted on a per sector basis. If three sectors are installed at once, some of the central costs (e.g., FCC permit fees, rental, etc.) are reduced on a per sector basis. This, however, is not considered here.

The ground networking costs given above are those that are incurred by a carrier buying from LDD. It is assumed that the carrier adds an additional markup of 15% before selling service to a subscriber. Also, it is assumed that one carrier port is provided for every subscriber port.

Point-to-Multipoint Monthly Costs For A Single Circuit Per Location:

The elements of Table 3.1-19 are derived as follows, using 5 subscriber locations per sector as an example:

Capital Costs

Central Fixed Hardware	$117,500	
5 RS-232 Port Cards @ $875	4,375	
Total Central Hardware	$121,875	
Total for Five Subscribers Each with one RS-232 Port Card; 5 X $11,500	$ 57,500	
Total Hardware		$179,375

Central Shipping and Installation	$ 15,000	ORIGINAL PAGE IS OF POOR QUALITY
Subscribers (5) Shipping and Installation; 5 X $4,000	20,000	
Total Central and Subscriber		$ 35,000
FCC Permit Fee		$ 9,000
Total Capital Costs		$223,375

Monthly Cost to Carrier

Maintenance Per Month (.15 X 179,375/12)	$2,242.19	
Central Monthly Rental	150.00	
Maintenance and Rent Per Month	$2,392.19	
Maintenance and Rent Per Month Per Subscriber		$ 478.44
Capital Authorization Per Subscriber (.0265 X 223, 375/5)		$1183.89
Total Monthly Cost Per Circuit to Carrier		$1662.33
Carrier Mark-up (15%)		249.35
Monthly Cost to Subscriber		$1911.68

Table 3.1-19 shows the monthly costs, assuming that each subscriber has a single RS-232 port. The monthly costs for a single RS-449 port per subscriber can be obtained from Table 3.1-19 by the procedure described below. Only one port card cost is included because the subscriber RS-449 card is included in the cost of the subscriber equipment.

- A central port costs ($1,100 - $875) = $225 more
- Hence, to 225 X 0.0265 (capital amortization) add $\frac{225 \times 0.15}{12}$

for maintenance to arrive at the total additional monthly cost of $8.77, as shown in Table 3.1-20.

It is noted that with RS-449 port cards, which implies 56 kbps circuits, a maximum of 30 circuits can be located in a sector.

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Table 3.1-19. Calculation of Monthly Costs (in Dollars) With One RS-232 Port Per Location

NUMBER OF LOCATIONS PER SECTOR	5	10	20	40	60	80	100	130
CENTRAL HARDWARE	121.875 K	126.25 K	135 K	152.5 K	170 K	187.5 K	205 K	231.25 K
SUBSCRIBER HARDWARE	57.5 K	115 K	230 K	460 K	690 K	920 K	1150 K	1495 K
TOTAL HARDWARE	179.37 K	241.25 K	365 K	612.5 K	860 K	1107 K	1355 K	1726.5 K
CENTRAL AND SUBSCRIBER SHIPPING	35 K	55 K	95 K	175 K	225 K	335 K	415 K	530 K
TOTAL CAPITAL COST (INCL. 9K FCC PERMIT FEE)	223.37 K	305.25 K	469 K	796.5	1124 K	1451 K	1779 K	2265.25 K
MAINTENANCE PER MONTH & CENTRAL NODE RENT	478.4	316.6	235.6	195.2	181.7	174.9	170.9	167.1
CAPITAL AMORTIZATION	1183.9	808.90	621.4	527.7	496.4	480.8	471.4	461
TOTAL MONTHLY COST PER CIRCUIT TO CARRIER	1662.3	1124.96	857.0	722.9	678.7	655.7	641.3	628.1
MONTHLY COST PER SUB-SCRIBER	1911.6	1293.7	985.55	831.33	779.81	754.05	737.49	722.31

Table 3.1-20. Monthly Costs (in Dollars), With One RS-449 Port Per Location

NUMBER OF LOCATIONS	MONTHLY COST PER CIRCUIT TO CARRIER	MONTHLY COST PER SUBSCRIBER
5	1671.07	1921.73
10	1133.73	1303.78
20	865.77	995.63
40	731.67	841.42
60	686.87	789.90
80	664.47	764.14
100	650.07	747.58
130	636.87	732.40

Point-to-Multipoint Monthly Costs For Two Circuits Per Location:

Table 3.1-21 gives the monthly cost per circuit assuming that each subscriber location has two RS-232 ports. The monthly costs if each subscriber location were to be equipped with two RS-449 ports can be derived from Table 3.1-21 as follows:

- Additional cost of the port cards = 3 X ($1,100 - $875) = $675
- Hence, to 675 X 0.0265 add $\frac{675 \times 0.15}{12}$ which gives $26

in addition to the monthly costs in Table 3.1-21, as shown in Table 3.1-22.

Point-to-Point Radios

Assumptions: The following assumptions apply to the point-to-point radio costs:

1. Five year amortization with a 20% cost of money, yielding a 0.0265 conversion factor to a monthly basis.
2. Maintenance costs - 15% of hardware costs.
3. Rent for the central site - $150/month.
4. Shipping and installation charges - $8,000 per link.

Table 3.1-21. Calculation of Monthly Costs Per Circuit (in dollars) With Two RS-232 Ports Per Subscriber Location

NUMBER OF SUBSCRIBER LOCATIONS	5	10	20	40	60	75
CENTRAL HARDWARE	126.25 K	135.0 K	152.5 K	187.5 K	222.5 K	183.125 K
SUBSCRIBER HARDWARE	61.875 K	123.75 K	247.5 K	495 K	742 K	928.125 K
TOTAL HARDWARE	188.125 K	258.75 K	400 K	682.5 K	965 K	1111.25 K
CENTRAL AND SUBSCRIBER SHIPPING	35 K	55 K	95 K	175 K	225 K	335 K
TOTAL CAPITAL COST (INCL. 9K FCC PERMIT FEE)	232.125 K	322.75 K	504 K	866.5 K	1229 K	1435 K
MAINTENANCE PER MONTH & CENTRAL NODE RENT (PER CIRCUIT)	250.2	169.2	128.8	108.5	101.8	93.6
CAPITAL AMORTIZATION (PER CIRCUIT)	615.1	427.6	333.9	287.0	271.4	253.5
MONTHLY COST (PER CIRCUIT) TO CARRIER	865.3	596.86	462.7	365.5	373.2	347.1
MONTHLY COST PER CIRCUIT TO SUBSCRIBER	995.09	686.32	532.10	454.82	429.18	399.16

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5. FCC permit fees - $9,000.

6. The following costs are assumed per non-redundant link, based on currently available equipment:

   a. $10,000 to
   b. $30,000

7. The cost of a MUX/DEMUX is $10,000 per pair, plus $500 per port card.

8. Carrier mark-up of 15%.

Table 3.1-22. Monthly Costs (in Dollars), With Two RS-449 Ports Per Subscriber Location

NUMBER OR SUBSCRIBER LOCATIONS	MONTHLY COST PER CIRCUIT TO CARRIER	MONTHLY COST PER CIRCUIT TO SUBSCRIBER
5	891.3	1024.99
10	622.8	716.22
20	488.70	572.0
40	421.5	484.72
60	399.20	459.08
75	373.1	429.06

Monthly Costs For Single Circuit Per Location:

The cost per circuit to the carrier for point-to-point radios supporting n circuits is (no MUX/DEMUX required):

$$(18{,}000 \text{ or } 38{,}000) \times 0.0265 + \frac{0.15\ (10{,}000 \text{ or } 30{,}000)}{12}$$

$$+ \frac{150 + 9000 \times 0.0265}{n}$$

This is:

$$\$602 + \frac{388.50}{n}, \text{ if link costs } \$10{,}000,$$

or

$$\$1382 + \frac{388.50}{n}, \text{ if link costs } \$30{,}000.$$

With a carrier mark-up of 15% the monthly cost per subscriber is

$$\$692 + \frac{446.77}{n}, \text{ if link costs } \$10{,}000,$$

or

$$\$1589.3 + \frac{446.77}{n}, \text{ if link costs } \$30{,}000.$$

Monthly Costs For Two Circuits Per Location:

At this point the cost of a MUX/DEMUX and its port cards needs to be added. Therefore, to the above add

$$12{,}000 \times 0.0265 + \frac{12{,}000 \times 0.15}{12} = \$468.$$

Thus, the cost per circuit including carrier mark-up is now

$$\$615 + \frac{223.38}{n}, \text{ if link costs } \$10{,}000,$$

or

$$\$1063.75 + \frac{223.38}{n}, \text{ if link costs } \$30{,}000.$$

TELCO/AT&T Type 100 Wire Facilities

The monthly cost analysis shown in Table 3.1-23 was derived from AT&T tariffs, cost for wire pair modems, and assumptions concerning annual maintenance fees.

Table 3.1-23. Monthly Cost of TELCO/AT&T Wire Facilities

	W2 (9.6 kbps)	W3 (56 kbps)
Monthly leased charges including conversion to W2/W4	$ 29.92	34.84
Non-Recurring charges amortized over 5 years	0.49	0.57
Digital Modems	$ 5,168	$ 5,440
25% shipping, installation	$ 1,292	$ 1,360
Amortized Monthly modem costs	$ 171.19	180.20
Annual modem maintenance costs	$ 969	$ 1,020
Monthly modem maintenance costs	80.75	85.00
Total Monthly Cost	$ 282.35	$ 300.61

Ground Networking Inputs to the 30/20 GHz CPS Cost Model

In order to perform a comprehensive trade-off analysis of the alternatives being considered for CPS ground networking, the costs for such services must first be put into a format by which effective comparisons may be made. One such baseline format is the Equivalent Voice Trunk Circuit (EVTC), as this is the finest granularity for which the transponder may be economically channelized. The intent of this baseline cost unit is to express all servives in terms of single voice circuits. In fact, analog voice grade lines remain the best alternative for providing a small number of local loops.

A T1 rate unit of traffic is perhaps more useful in terms of the available ground networking concepts. Table 3.1-24 summarizes the Subscriber and Transmission Media costing data generated during the course of this investigation in terms of the smallest unit of capacity which is independent of the loading on the links. In other words, the costs provided describe the basic increments of hardware available and do not depend on whether or not the links are used to capacity.

Table 3.1-24. Installed Cost of Ground Networking For Subscriber Equipment

	Distance from Central (MI)					
	1	2	3	4	5	6
T1 Point-to-Point Microwave Radio	5,000	6,000	14,000	14,000	14,000	20,000
T1 Fiber Optic Cable	21,000	24,000	27,000	32,000	36,000	40,000
T1 Coaxial Cable*	12,000	21,000	30,000	39,000	48,000	57,000
56 Kbps Point-to-Multipoint Microwave Radio	17,000	12,000	12,000	12,000	12,000	12,000
56 Kbps Point-to-Multipoint Microwave Radio	6,000	6,000	6,000	6,000	6,000	6,000
56 Kbps DDS**	2,537	2,537	2,537	2,537	2,537	2,537

*Dedicated routed cable

**Assumes 2 links at indicated distance in same serving area ($/mo.)

In this costing analysis, no provision has been made for the sharing of resources, such as a common coaxial cable or fiber optic link. This is because user distributions cannot be accurately predicted in order to optimize the ground networking solution. Table 3.1-25 presents the equipment cost per circuit at the master network concentrator for each of the ground networking categories. The fixed cost is for facilities, connections to the earth station, and common hardware. Cost per circuit is taken as the additional capital and installation for each circuit.

Table 3.1-25. Equipment Cost at Master Network Concentrator

TECHNOLOGY	FIXED COST	COST PER CIRCUIT
T1 Point-To-Point Microwave Radio	$ 5,000	$ 16,000
T1 Fiber Optic Cable	5,000	17,000
T1 Coaxial Cable*	5,000	1,000
56 Kbps Point-to-Multipoint Microwave Radio	117,000	12,000
56 Kbps Point-to-Multipoint Coaxial Cable	55,000	1,000
56 Kbps DDS**	208	208

*Dedicated route cable
**Assumes 2 links at the indicated distance in the same serving area ($/mo)

Note that the costs for both radio and cable point-to-multipoint service are based upon the second generation hardware now under development for RAPAC and CAPAC. The systems described in Section 3.1.2 operate on the same principles but are lower capacity systems than those under development.

The T1 circuit costs (Tables 3.1-24 and -25) for the various point-to-point technologies were derived from the following data:

1. T1 Point-to-point radio equipment includes:

   a. 1 Mile: Raycon II with 2 foot antenna
   b. 2 Miles: Raycon II with 4 foot antenna
   c. 3-5 Miles: Terra-com-loral TCM-416 E with 2 foot antenna
   d. 6 Miles: Terra-com-loral TCM-416 E with 4 foot antenna

2. T1 Fiber Optic Cable Link Equipment:

   a. DCC LTR module with 2T1 capability: $16,000
   b. Fiber: $4,000 per mile

3. T1 Coaxial Cable

   a. Scientific Atlanta Modem: $3,000
   b. Coaxial cable: $9,000 per mile

The point-to-multipoint services (Tables 3.1-24 and -25) assume minimal charges for the coax media itself and for frequency coordination (for microwave). The hardware costs are based on recent quotes from vendors. DDS service is based upon recent AT&T tariffs; costs given are the monthly recurring charges.

3.2 CPS EARTH STATION SYSTEM ISSUES

The key subsystem elements which must be considered in the design of a CPS earth station are identified in Figure 3.2-1. The cost of providing end-to-end customer Premise Service is the major factor affecting the viability of providing such service, in the face of competing technological approaches. Use of existing technology typically leads to earth station unit procurement costs ranging from $100,000 to $800,000. Clearly, the requirement exists for development of new technology and networking concepts that can lead to substantial reductions in ground terminal cost components. Additionally, the costs associated with operation and maintenance of the network and its component earth stations are significant and should be minimized within bounds of providing adequate levels of service. Methods to achieve highly reliable operation with unmanned CPS stations need to be defined, which lead to achievable Mean Times Before Failure (MTBF) and Mean Time To Repair (MTTR) for CPS ground equipments.

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CPS EARTH TERMINAL SYSTEM CONSIDERATIONS

- ANTENNA SUBSYSTEM
  - EFFICIENCY
  - SURFACE TOLERANCE
  - POINTING ACCURACY (STEPTRACK VS. MONOPULSE)
  - FEED AND DIPLEXER LOSSES
- RECEIVER
  - NOISE FIGURE
  - BANDWIDTH
  - NEED FOR REDUNDANCY
- TRANSMITTER
  - COST
  - BANDWIDTH
  - MODE OF OPERATION (SATURATED VS. LINEAR)
  - NEED FOR REDUNDANCY
  - OUTPUT POWER VARIATION, PEAK POWER, DUTY CYCLE
- MODEM
  - CARRIER AND CLOCK ACQUISITION AND TRACKING
  - COST
- DATA HANDLING
  - INTERFACE
  - MULTIPLEXING
  - TIMING

Figure 3.2-1. CPS Earth Terminal System Considerations

Antenna Subsystem

The antenna subsystem consists of the reflector and subreflector (if used), the feed, the pedestal, and perhaps pointing control equipment. Key parameters are identified in Figure 3.2-1, with surface tolerance requirements being the most critical for 30/20 GHz technology development. The accuracy of a reflector surface and the conditions under which that surface must be maintained exert a large influence on the performance and cost of a CPS earth station. The trade off involved is not simply one of performance, but also includes rate of cost increase as the surface becomes more accurate. Additionally, as antenna performance improves, the antenna diameter may be reduced slightly to maintain the same nominal gain which, in turn, affects cost. Generally the antenna parameters which have been identified are not unique to Ka band. Within the antenna requirements imposed by the CPS network, none of these should present unreasonable design problems. It is expected that, given the very narrow beamwidths available from antennas of reasonable size at Ka band, pointing accuracy may be a more stringent requirement than at other operational frequencies.

IF/RF Subsystem

The major components of the RF/IF subsystem are Low Noise Amplifier (LNA), Frequency Converters, and High Power Amplifier (HPA).

A major issue in the design of the CPS earth stations is the selection of an HPA, particularly if it is to be used to overcome the severe rain fading at Ka band. It is expected that the HPA will represent the largest single cost item in a typical CPS earth station. In a TDMA system, the peak power required of the HPA will be higher than that required for an FDMA uplink. However, it may be possible to take advantage of the low duty cycle of TDMA bursts to reduce the cost of the HPA power supply and cooling system, which mainly depend upon the HPA's average power. If uplink power control is to overcome rain fades, HPA output power must be controllable upon command. This is necessary because the usual practice of including rain fade margins in the link budgets, and sizing the earth station HPA accordingly, produces a great deal of co-channel interference. In an FDMA configuration the HPA must be operated with considerable output backoff (linear mode) in order to minimize intermodulation distortion within the HPA. Another approach would be to amplify each uplink channel with a separate HPA of lower rated power and then combine the outputs

before the antenna feed. This is generally a more costly approach when several carriers are involved.

The key trade off involved with LNA design and implementation is its cost vs. noise temperature. This assumes that the gain of the LNA is large, so that its noise figure tends to dominate. Several technologies exist today for LNA implementation. It is expected that the service demand created by frequency congestion at lower frequency bands will lead to the development of LNA and mixer technology for Ka band which is comparable to the Ku band technology which exists today.

The primary issue in modem development is cost, not feasibility. CPS modem development is not dependent on RF link operating frequency, except for the IF output bandwidth, which tends to increase at Ka band. Efforts directed towards the simplification of carrier and clock acquisition and tracking would be most helpful in reducing the modem cost. Development of VLSI modems will simplify maintenance and reduce equipment costs, particularly considering the large quantities of earth stations expected to be used in a CPS Network.

Baseband and Terrestrial Interface Subsystem

This subsystem performs several functions, chief amongst which are connection to the terrestrial network via ports of various kinds, assembly of messages or channels for transmission, expansion and compression buffering in TDMA configurations, elastic buffering in all cases to compensate for satellite motion, and monitor and control of station status and link performance.

When Demand Assignment Multiple Access (DAMA) is added to the system, this baseband equipment becomes more complex. Switching functions must then be added to the station's capability, as well as means for interpreting requests for bandwidth and communication over the common signaling channel.

3.2.1 FUNCTIONAL DESCRIPTION OF AN SS-TDMA/FIXED BEAM EARTH STATION

The SS-TDMA concept is intended to provide full communications connectivity among a large number of CPS terminals which are located in individual spot beam antennas. Figure 3.2-2 is a functional diagram of the SS-TDMA/Fixed Beam transponder. Connectivity among the multiple spot beams is provided by means of an IF switch whose cycle pattern is synchronized to the TDMA frame. A representative switch/frame combination is shown in Figure 3.2-3. The burst

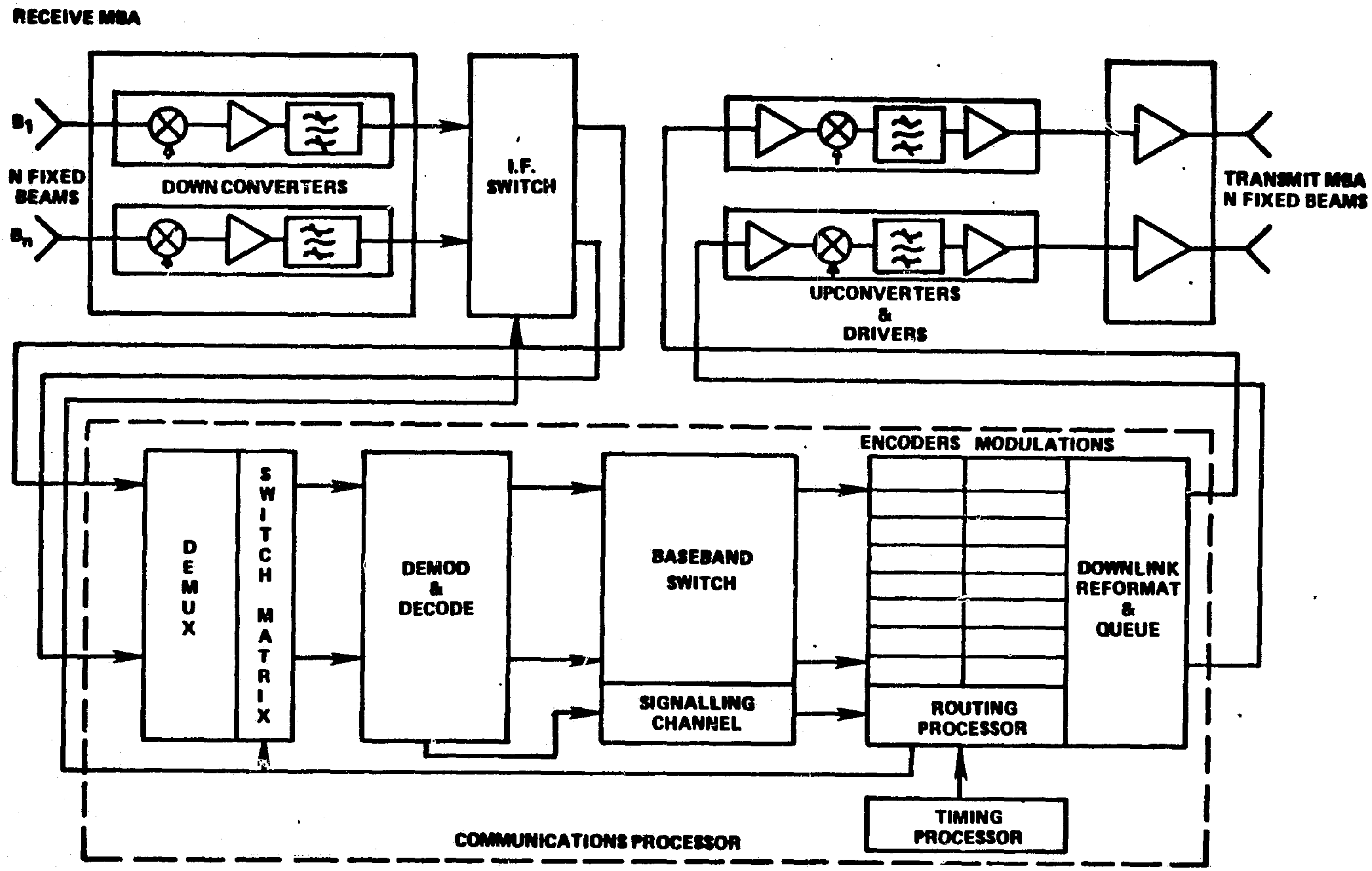
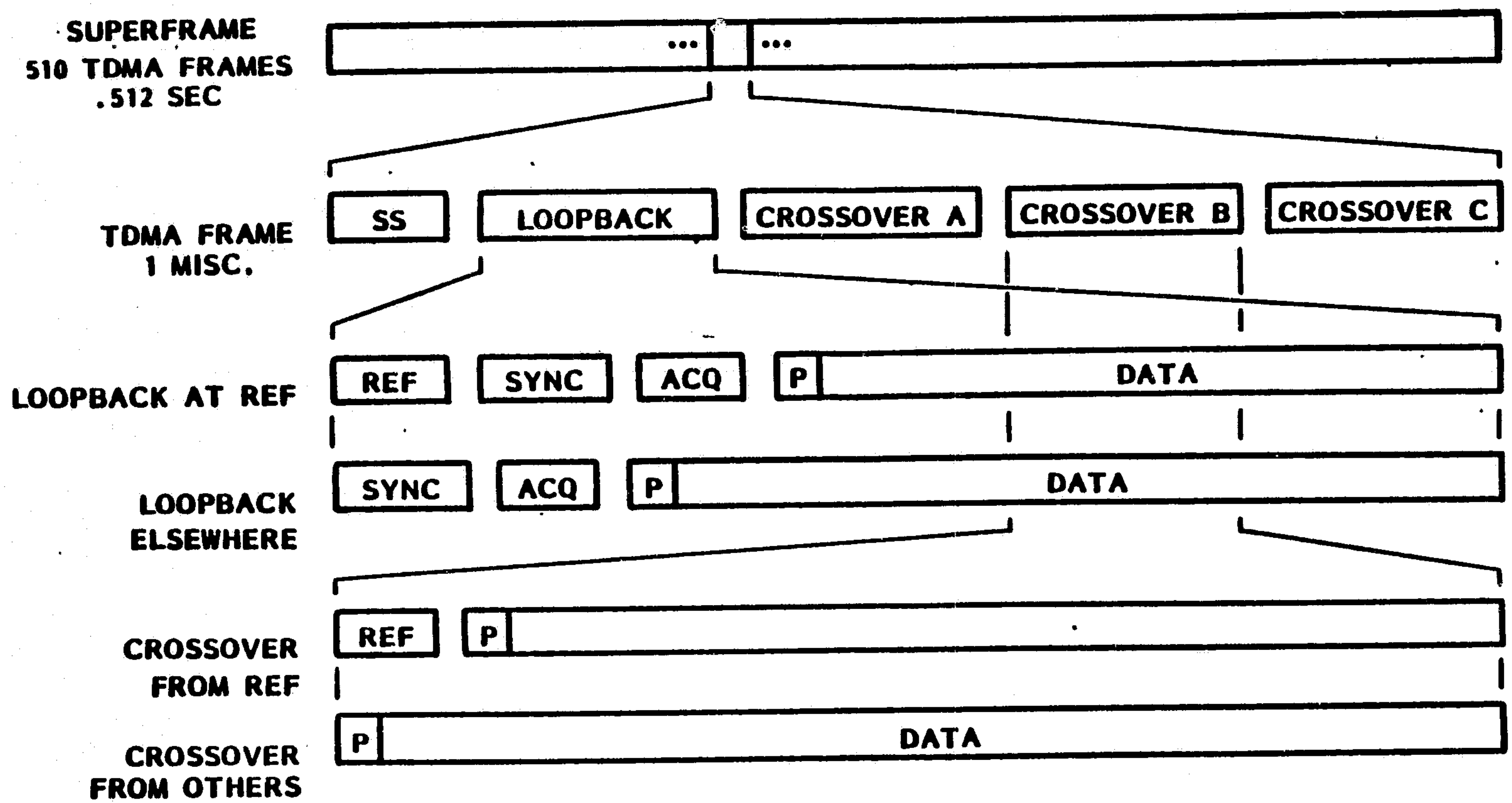


Figure 3.2-2. SS-TDMA Payload Concept



SS = SATELLITE SWITCH SYNCHRONIZATION
LOOPBACK = IF SWITCH STATE WHICH CONNECTS STATIONS IN THE SAME BEAM
CROSSOVER = IF SWITCH STATE WHICH CONNECTS STATIONS IN DIFFERENT BEAMS
REF = ALTERNATES BETWEEN LOCAL AND DIVERSITY REFERENCE BURSTS
SYNC = USED FOR LOCAL BURST SYNCHRONIZATION DURING LOOPBACK
ACQ = USED FOR INITIAL ACQUISITION
P = PREAMBLE AND UNIQUE WORD
DATA = DATA BURST - 256 MBPS

Figure 3.2-3. Representative SS-TDMA Frame Structure

rate chosen for the CPS station TDMA links depends upon the aggregate throughput of the "average" earth station in the network, i.e., upon the degree of ground networking concentration which is performed. This is due to the fact that the TDMA burst rate is the dominating cost driver for the earth station. Two polar examples will clarify this concept. One case corresponds to a traditional trunking station concentrating a very large number of users onto a high burst rate TDMA terminal. While this configuration requires a high cost terminal, this cost is shared among a large number of users. The other extreme corresponds to one earth station per user site. In order to maintain the same cost per customer, the burst rate of the terminal must be much lower. The aggregate traffic of the network would be accommodated through the use of a FDM/TDMA channelization scheme in this case.

The selection of the frame time requires the consideration of a number of parameters. Between frames, the data that arrives at an earth station must be stored until the next frame arrives. The input rate to this storage or memory may be slow, corresponding to the rate entering the TDMA station of each of its terrestrial terminals, and the read out rate very rapid, corresponding to the TDMA satellite bit rate which may be several hundreds of megabits per second.

On the receive side of the same terminal, the reverse is required. Data is written into the memory at the satellite bit rate and more slowly read out into the terrestrial interconnect ports. One hundred megabits per second corresponds to an access time of 10^{-8} seconds (10 nanoseconds). Solid state (static) random access memories (RAM) are available in this extreme range. If several memories are used in parallel, it is possible to multiplex the outputs such that the speed demanded of any one is reduced by the number of parallel memories.

The cost of very high speed memories is not falling significantly, due to packaging limitations in terms of chip density and heat dissipation. Thus, 120 to 250 Mbps memories could be built using parallel memories, typically 16 bits wide, to avoid the order of magnitude premium of the high speed memory devices. However, the support logic to provide such serial-to-parallel-to-serial processing limits some of the cost per bit gain, probably holding the installed cost per bit near $0.02

Another aspect in the TDMA frame trade-off is the frame efficiency, which is given in the following equation:

$$E = (CF-NGC-NP)/CF$$

Where:

E= TDMA Frame efficiency
C= Gross bit rate

F= Frame period
N= Number of stations in the frame
G= Guard time
P= Number of preamble bits.

TDMA frame efficiency corresponds to the total percentage of the TDMA burst rate that carries user data.

Frames beyond 50 msec add additional delay in the compression and expansion processes, thus adding to the satellite round trip delay of 0.25 second. This delay may introduce problems beyond those normally associated with voice circuits; these extend to certain higher speed data circuit applications.

Three constraints have been presented for the selection of the frame length: memory costs, efficiency and delay. The delay constraint imposes frame lengths below 50 msec. The memory cost constraint shows a generally linear increase in memory costs with frame length. The efficiency constraint shows a marked penalty for frames shorter than 1000 microseconds. Because of the large number of stations anticipated in the CPS network, memory costs are of extreme significance, and thus a shorter frame length may be more appropriate, even though the efficiency may drop below 90%. The SS-TDMA earth station will accommodate digitized voice, data, and compressed digital video. The basic traffic is assumed to be a DS-1 format T1 data stream, which consists of 24 voice or data channels at or below 64 kbps. Compressed digital video is also assumed to be carried at a T1 or lower rate. It is recommended that the TDMA frame rate be some multiple of the DS-1 superframe rate (1.5 msec) to simplify the formatting/deformatting process. The examples of burst rates considered as input to the costing analysis are 10, 60, and 256 mbps. Any of these rates are viable for the SS-TDMA/Fixed Beam concept, but aggregate throughput requirements dictate a 256 Mbps burst rate for the scanning beam TDMA.

The satellite switch, as it cycles through its programmed pattern once per frame, provides each uplink access to all downlink spot beams, including a loopback beam. This loopback mode can be used to obtain closed loop synchronization of burst positioning. The loopback mode also provides a path by which BER performance can be measured to determine the presence of fading conditions. The satellite switch requires that each station transmit multiple bursts per frame to obtain connectivity to more than one downlink spot beam. This interrelation between the IF switch cycle and the TDMA network plan adds a measure of complexity to the circuit assignment algorithm. It is recommended that spot beam interconnection bandwidth allocation, (switch cycle) not be made on a call-by-call basis. Updates to the traffic matrix should be made on a time scale of many superframes (several seconds), at a minimum. Demand assignment can occur within this traffic matrix on a call-by-call basis.

A block diagram of an SS-TDMA/Fixed Beam earth station is shown in Figure 3.2-4 and an equipment list is found in Table 3.2-1. The IF/RF portion is discussed in a later subsection, as is the case for all the other configurations.

3.2.2 FUNCTIONAL DESCRIPTION OF A SS-TDMA/SCANNING BEAM EARTH STATION

The earth station design for this baseband processing payload concept is very similar in structure to that for SS-TDMA/Fixed Beam. The major difference is that a 256 Mbps or higher burst rate is required due to the short dwell time of the scanning beam. In order to minimize the delay incurred through the processing of TDMA signals, a beam must scan the entire sector of CONUS assigned to it in one TDMA frame. Other primary differences are in the area of call assignment, burst positioning, and synchronization. Multiple bursts per station per frame are no longer required due to the presence of baseband processing and routing functions. This simplifies the call assignment process, as well as reducing the duty cycle of the HPA relative to SS-TDMA/Fixed Beam. This may lead to cost savings in terms of the required power supply and a possible reduction in cooling requirements.

The scanning beam TDMA payload concept, depicted in Figure 3.2-5, eliminates the potential for open loop synchronization, as the loopback mode includes an unpredictable (i.e., variable) processing delay. An open loop synchronization algorithm must thus be adopted, controlled either from the satellite itself or from the Network Control Center.

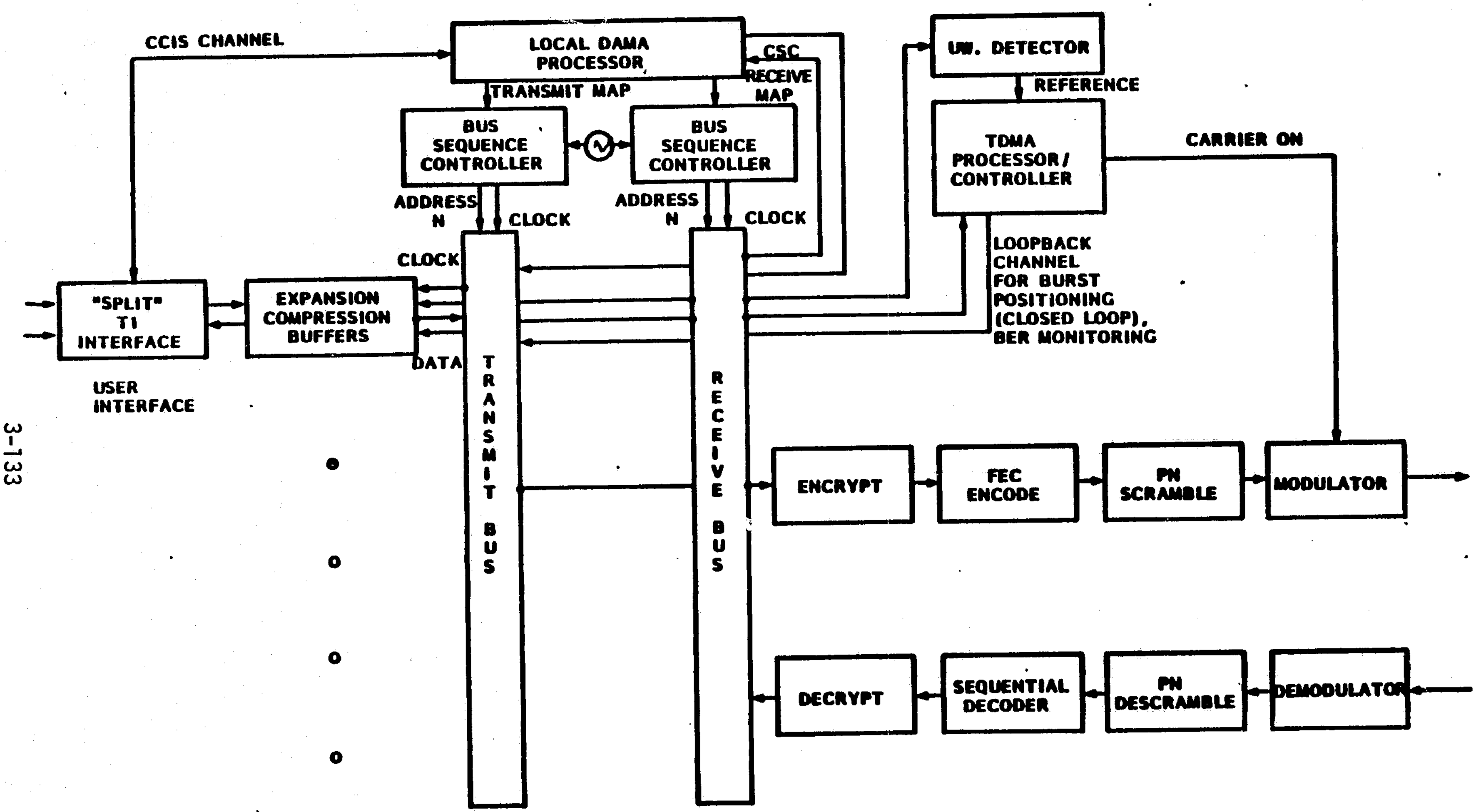


Table 3.2- 4. Earth Station and Satellite Average EIRP Requirements

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Table 3.2-1. Equipment List for a SS-TDMA/Fixed Beam Earth Station

BASEBAND -Split T1 Port Cards -Network Memory Sequencer -Site Control Processor -Performance Monitoring Unit
10 or 60 Mbps BURST MODEM
FREQUENCY CONVERTER (Two Stage, Dual Conversion)
17 or 25 dBw COUPLED CAVITY TWT HPA
300°K GaAs FET LNA (Antenna Mounted)
4m DUAL POLARIZED ANTENNA -Transmit waveguide -Transmit Reject Filter
RACKS AND PATCHES
SHELTER (Evironmentally Controlled)

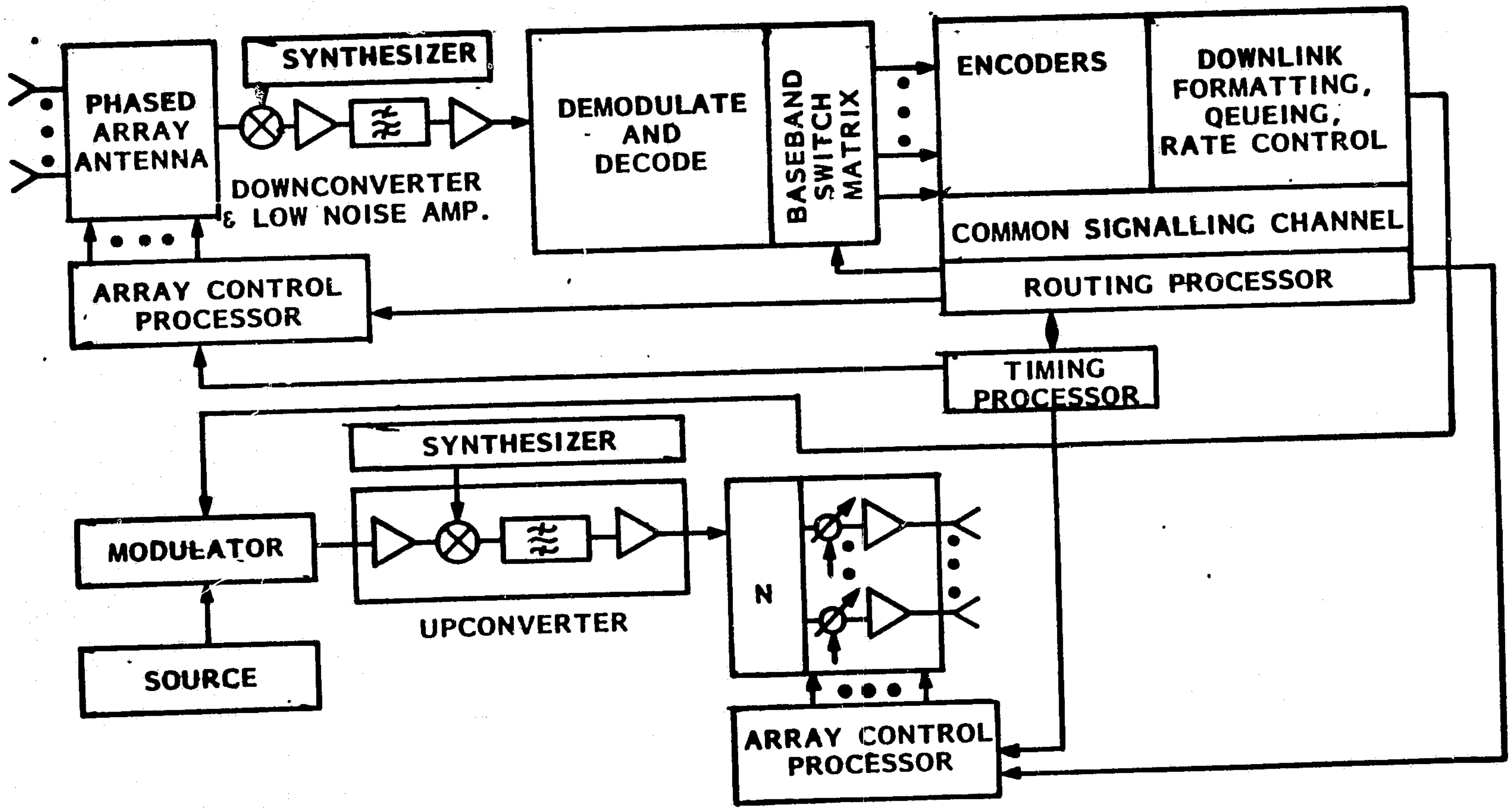

Figure 3.2-5. SS-TDMA/Scanning Beam Payload Concept

3.2.3 FUNCTIONAL DESCRIPTION OF A SS-FDMA EARTH STATION

The use of SS-FDMA presents the key alternative to a TDMA spacecraft concept. A block diagram of the SS-FDMA payload may be found in Figure 3.2-6. The system under consideration would have a minimum satellite channelization of 1.544 mbps, with the intent of providing connectivity in T1 increments. The main advantage of FDMA is that spacecraft communication links operate at a rate which closely matches the individual user rate. This tends to reduce peak transmitter power and buffering requirements, as compared with TDMA approaches.

The FDMA concept most effectively meets the goal of simple earth stations at the expense of a more complex satellite. This is particularly in harmony with the CPS concept. Unfortunately, the satellite IF switch becomes a limiting factor when the number of simultaneous accesses grows large, both in terms of implementation complexity and in terms of added noise from crosstalk in the switch.

Although the SS-FDMA earth station requires fewer new technology developments than would a TDMA earth station, the limitations begin to mount quickly, even when modest traffic forecasts are considered. A block diagram of the SS-FDMA earth station may be found in Figure 3.2-7 and an equipment list in Table 3.2-2. As is the case for all of the configurations, the IF/RF subsystem is dependent upon the station's availability and throughput requirements, and is discussed in a separate subsection. The major components shown are the terrestrial interface, the modems, frequency synthesizer, control processor, and the orderwire modem. The terrestrial interface provides the physical connection to the ground network and/or T1 switch, as well as a small amount of elastic buffering to compensate for satellite motion. The modems and frequency synthesizer should allow the earth station to access all of the channels which are available in its beam. The selection of an uplink and downlink frequency pair will be arbitrated by the central DAMA processor through requests and acknowledgments over the orderwire. The particular frequency pair chosen specifies the path through the IF switch, as well as the beam-to-beam connectivity. The control processor commands the synthesizer, based upon orderwire instructions, and also monitors local equipment status.

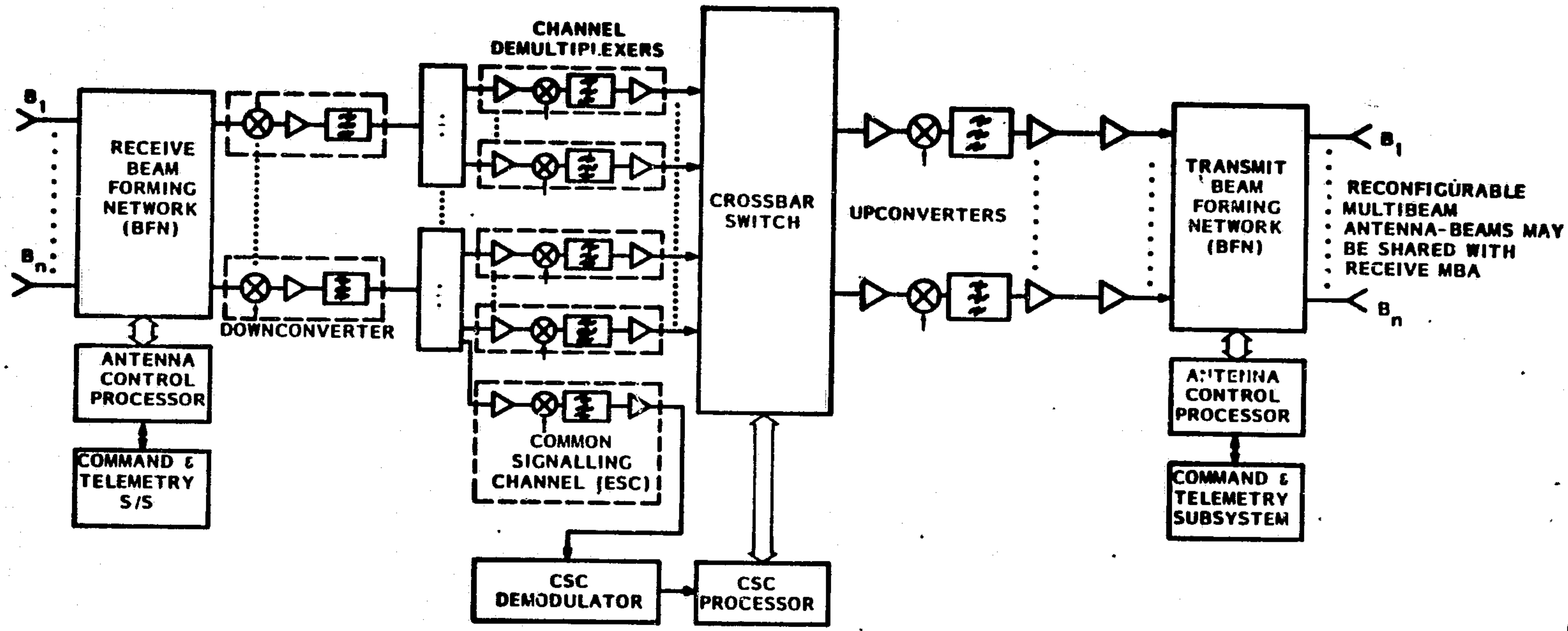

Figure 3.2-6. SS-FDMA Payload Concept

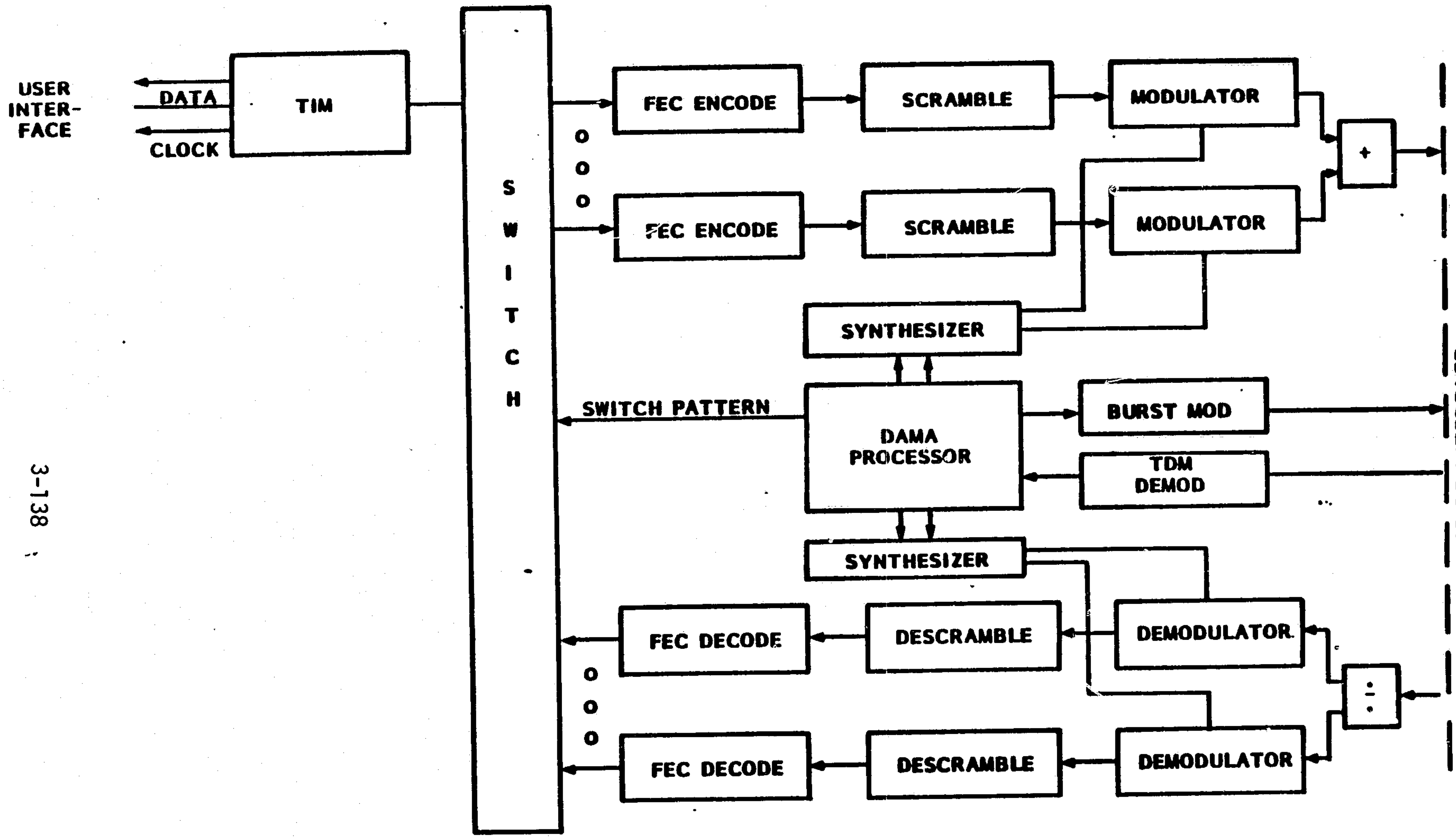

Figure 3.2-7. Block Diagram of an SS-FDMA Earth Station

Table 3.2-2. Equipment List for an SS-FDMA Earth Station

BASEBAND
-T1 Interface Port Card
-Redundancy Switchover
-Performance Monitoring Unit
-DAMA and CSC Processor
-Power Supply
-Racks and Patches
-Reference Frequency Generation (Local Oscillator or from Downlink)
MODULATION
-Frequency Synthesizer
-1.544 Mbps Modems
-Redundancy Switchover
-CSC Modem
IF/RF
-Dual Two Stage Frequency Converter
-15 Watt HPA per T1 Channel
-300°K LNA
-Waveguide
-3m Antenna (Dual Polarized)
-Transmit Reject Filter
ENVIRONMENTALLY CONTROLLED SHELTER

3.2.4 FUNCTIONAL DESCRIPTION OF A HYBRID FDMA UP/TDMA DOWN EARTH STATION

The HYBRID payload configuration includes the use of a baseband processor to convert FDMA uplinks to TDMA downlinks (actually TDM) into each spot beam. A block diagram of this payload may be found in Figure 3.2-8. Frequency agile modulators are not required for routing, only for DAMA. Routing functions are provided aboard the spacecraft. As the entire downlink signal emanates from one transmitter with one timing source, the downlink would be more appropriately referred to as TDM, rather than TDMA. A block diagram of an earth station to be used with this payload concept may be found in Figure 3.2-9 and an equipment list in Table 3.2-3.

This station is basically a hybrid of the SS-FDMA and the processing TDMA configurations. The cost of the station can be reduced compared with that of the scanning TDMA because network burst synchronization is not required on the uplink. The signaling channel architecture becomes a bit complicated because half of it can be implemented on the TDM downlink, but the uplink side must be implemented through the use of a separate modulator.

3.2.5 IF/RF SUBSYSTEMS

This Section identifies the major components of the IF/RF subsystems and provides the appropriate sizing of the components for each class of earth station configuration. The Section begins with a system analysis of each component in terms of available technology and expected technology development, which is followed by an identification of the major cost, versus performance breakpoints. The components under discussion include antenna, feed and waveguide assembly, High Power Amplifier (HPA), Low Noise Amplifier (LNA), and Frequency converter.

Following the system description, link budgets are analyzed for each configuration. These analyses provide the basis for sizing the RF equipment including provision for the fade compensation discussed in the last section.

Antenna Subsystem

Surface accuracy and pointing accuracy are two key parameters which tend to be degraded with increasing frequency. Precision molding or spinning steps must be performed in the antenna manufacturing process in order to keep surface

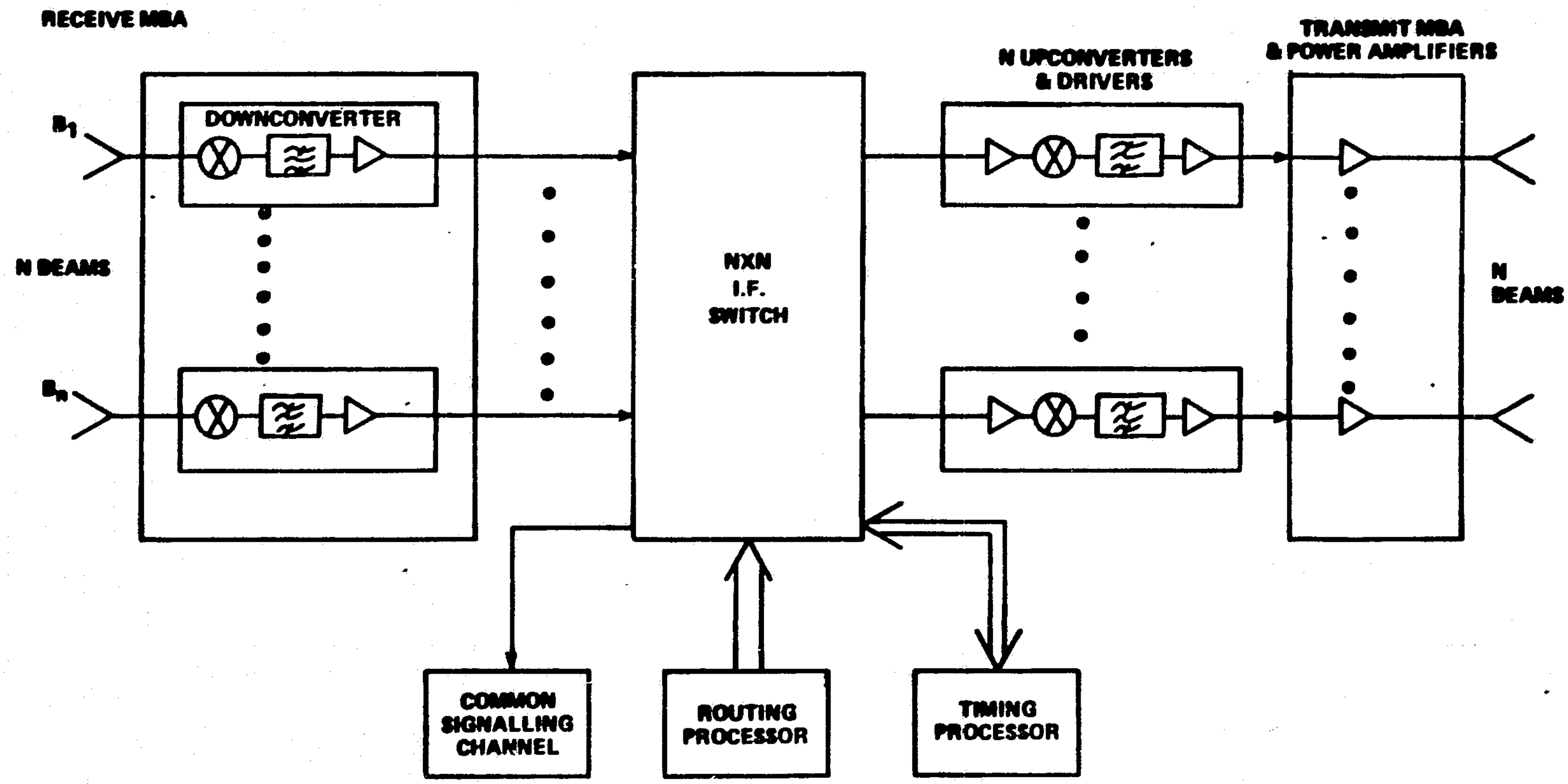

Figure 3.2-8. Hybrid FDMA/TDM Payload Concept

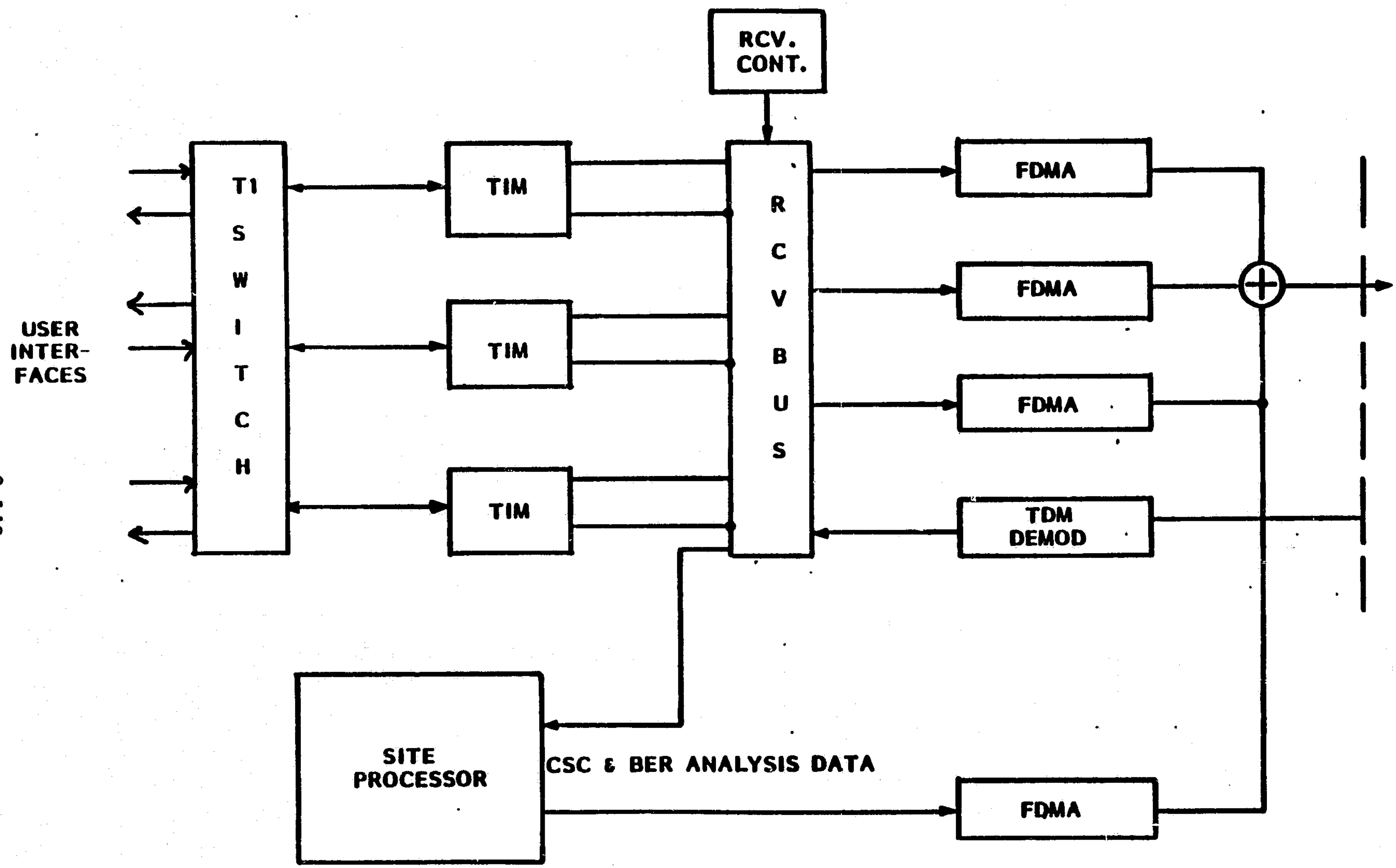

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Figure 3.2-9. Hybrid FDMA/TDM Earth Station Block Diagram

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Table 3.2-3. Equipment List for a HYBRID Earth Station

T1 PORT CARDS -Elastic Buffer on Transmit Side -Expansion Buffer on Receive Side -Synchronous Interface to the Ground Network
TDM RECEIVE BUS AND DEMULTIPLEXING CONTROLLER
SITE CONTROL PROCESSOR -Performance Monitoring -DAMA Request Processing
1.544 SERIAL MSK MODULATORS
10 or 60 Mbps SMSK DEMODULATOR
IF/RF -Frequency Converter -15 watts HPA -300°K LNA -4m Dual Polarized Antenna -Transmit Waveguide
RACKS AND PATCHES
ENVIRONMENTALLY CONTROLLED SHELTER

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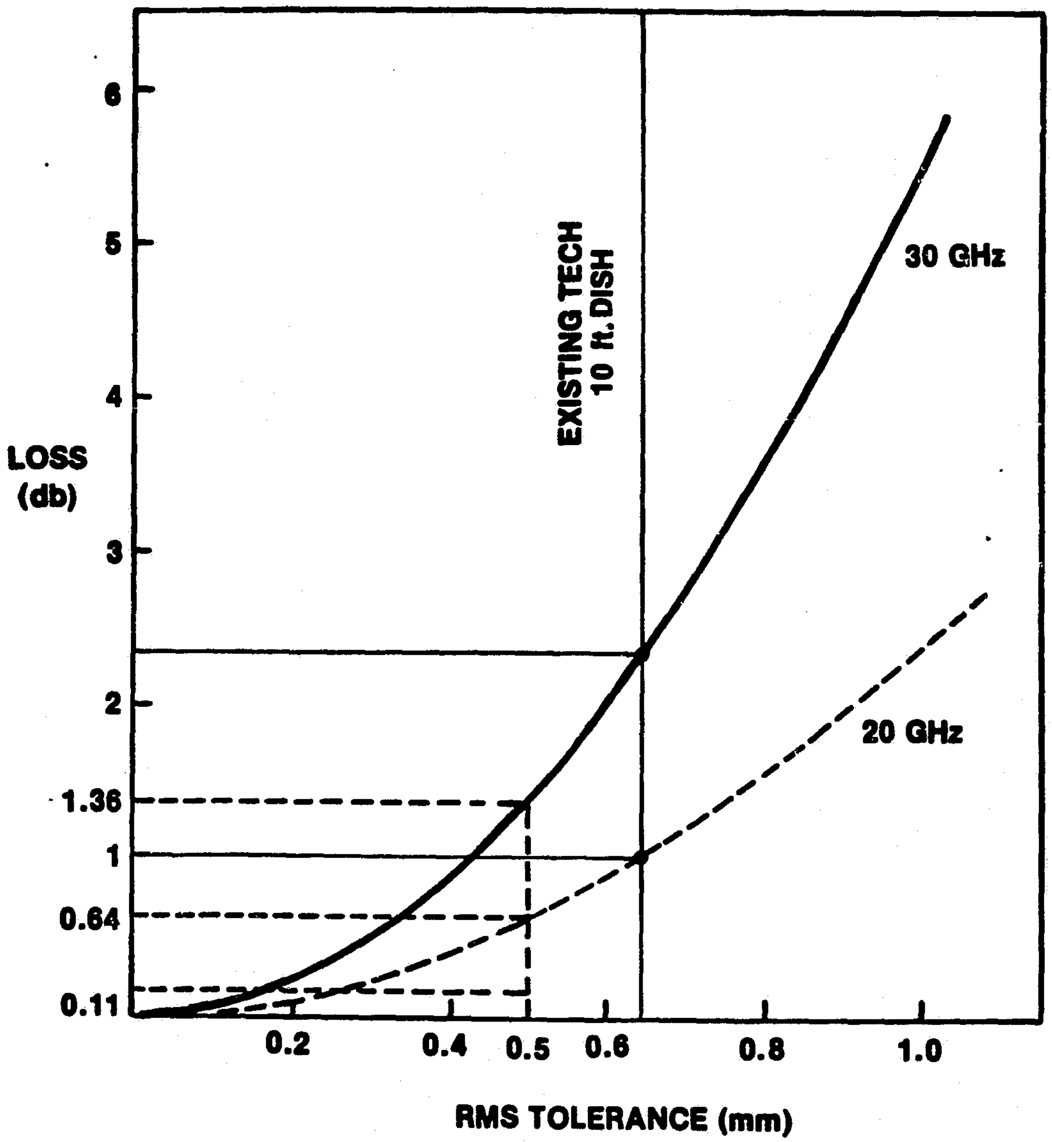

Figure 3.2-10. RMS Surface Loss

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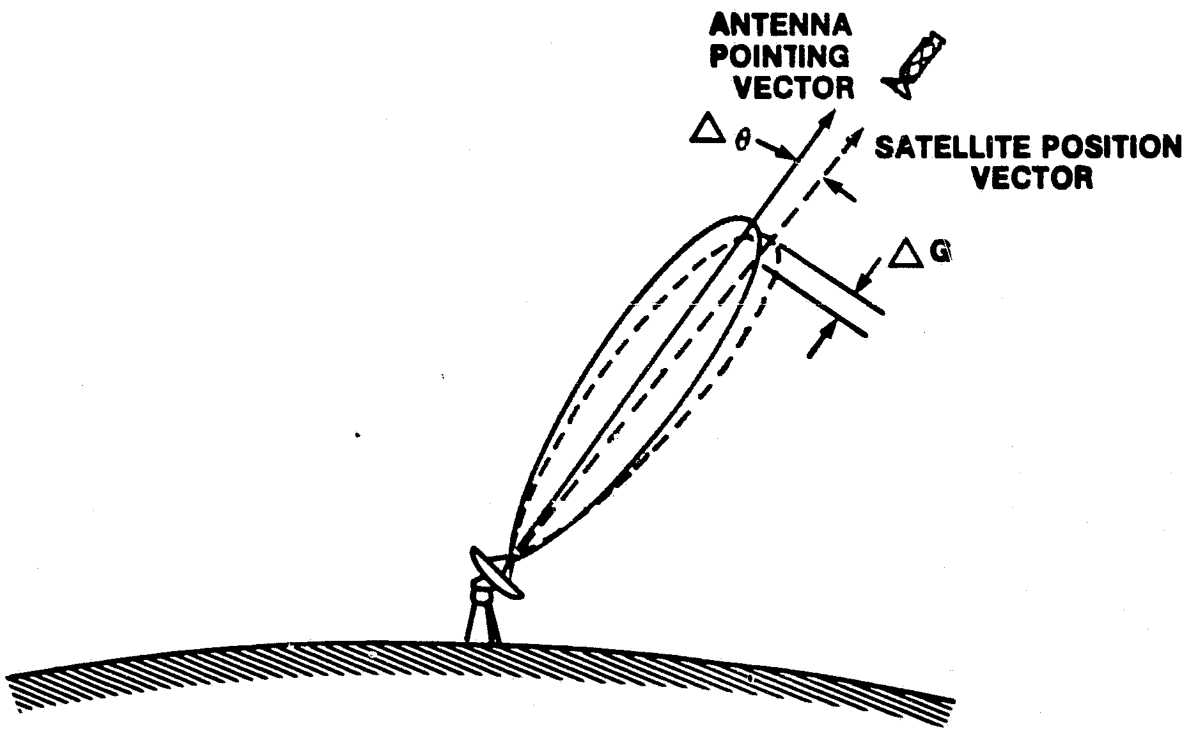


ΔG = ANTENNA TRACKING LOSS $= 12 \left(\frac{\Delta\theta}{\theta_3}\right)^2$ (db)

$\Delta\theta$ = ANTENNA TRACKING ACCURACY

θ_3 = ANTENNA HALF-POWER BEAMWIDTH

Figure 3.2-11. Antenna Loss and Relevant Tracking Parameters

scattering losses below 1 dB. Due to recently increased activity in the area of high frequency microwave radios, it is expected that surface losses (now averaging 2 dB at 30 GHz off the shelf) will soon be comparable to conventional C-Band technology antennas. Quantity production of small diameter antennas could make the price of such an antenna competitive with its C-Band analog. See Figure 3.2-10 for an indication of surface loss as a function of surface tolerance at 30/20 GHz.

Tracking accuracy refers to the precision with which the earth station antenna can be directed at the satellite. Figure 3.2-11 represents antenna loss and the relevant tracking parameters. Note that such loss at a given antenna diameter increases with frequency. This results due to the inverse relationship between beamwidth and frequency. A reasonable design goal is to keep pointing loss at less than 1.5 dB at 30 GHz. Within this design constraint, there will be an antenna diameter threshold above which some form of tracking must be used to remain within the 1.5 dB design constraint. Specifically, the pointing loss may be expressed as:

$$\Delta G = 1.76 \times 10^{-5} (\Delta \emptyset D f)^2 \text{ (dB)}$$

where ΔG is pointing loss, $\Delta \emptyset$ is tracking accuracy, in degrees, D is antenna diameter, in inches, and f is the operating frequency in GHz. For a 1.5 dB loss at 30 GHz:

$$\Delta \emptyset = \frac{9.73}{D}$$

It should be noted that the $\Delta \emptyset$ requirement is imposed by the station keeping accuracy of the satellite TT&C network. Note the stationkeeping capabilities of satellites have been improving with time. At one time, $\pm 1°$ of east/west tolerance was common. Based on the experience of Canada's Anik, most U.S. domestic satellites are controlled to within $\pm 0.1°$ of longitude (east/west) and latitude (north/south or inclination). Present day INTELSAT satellites are controlled within these dimensions and have an apogee/perigee difference of 30 km (or ± 9.3 miles out of 22,300 miles).

The stationkeeping goals for the SBS satellites are $\pm 0.03°$ in latitude and longitude. The interval between corrections is 7 days for latitude (north/south), 28 days for longitude (east/west), and 4 days under the worst conditions for attitude changes. Figure 3.2-12 shows the dimensions of the various error boxes. These dimensions are expressed in terms of linear units (kilometer) and in terms of time delay variations (microseconds).

If is assumed that the stationkeeping accuracy of the 30/20 GHz CPS satellite will be equivalent to the SBS design goal in the worst case, 0.03° accuracy, O is .06°. Therefore, when,

$$.06 \leqslant \frac{9.73}{D}$$

$$D \leqslant \frac{9.73}{.06} \qquad \text{(inches)}$$

$$D \leqslant 4.12 \qquad \text{(meters)}$$

the antenna pointing loss will be less than the design goal, and a fixed antenna mount can be used.

The feed and waveguide assembly should present no problems in implementation, save that the distances from the HPA to the reflector feed should be kept as short as possible to minimize attenuation (which increases as a function of frequency). It is expected that waveguide and feed losses can be kept below 0.5 dB with conventional technology. In areas with constant high humidity and/or extensive precipitation, a pressurized feed assembly may have to be installed in order to meet the 0.5 dB feed and waveguide loss criteria. This typically adds an order of magnitude to the cost of the feed.

High Power Amplifier

It is anticipated that this component will be the major cost element of all the earth station configurations. Specific technologies used to implement HPAs include Gallium Arsenide Field Effect Transistor, IMPATT Diodes, Helix Traveling Wave Tube Amplifier (TWTA) and Coupled Cavity TWTA.

As can be seen in the link budgets which follow, all configurations require power amplifiers with saturated output of greater than 5 watts at 30 GHz. Figures 3.2-13 and 3.2-14 demonstrate that GaAs FET and IMPATT diode amplifiers are not expected to be able to meet these requirements. The power

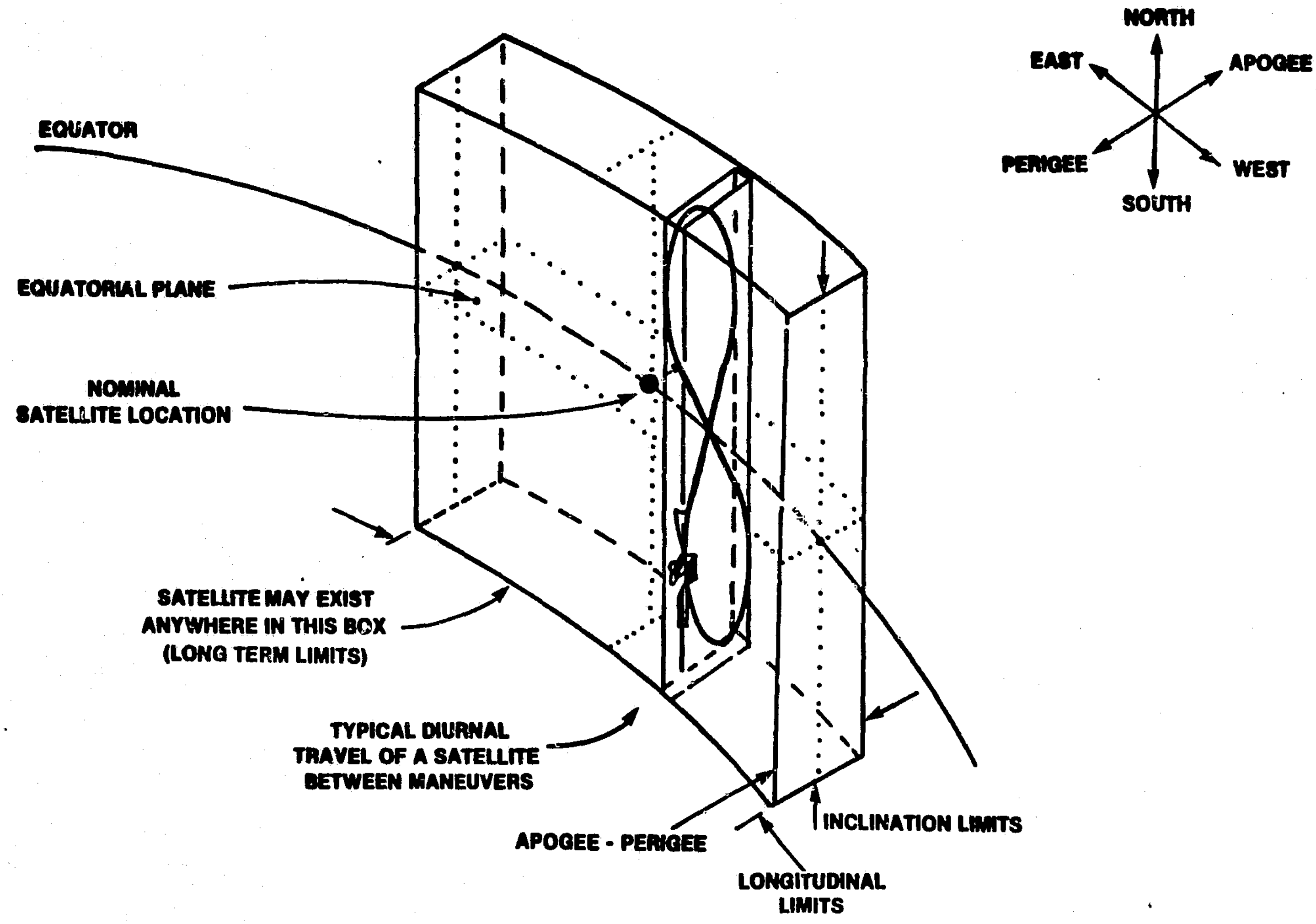


Figure 3.2-12. Minimum Time Delays Due To Stationkeeping

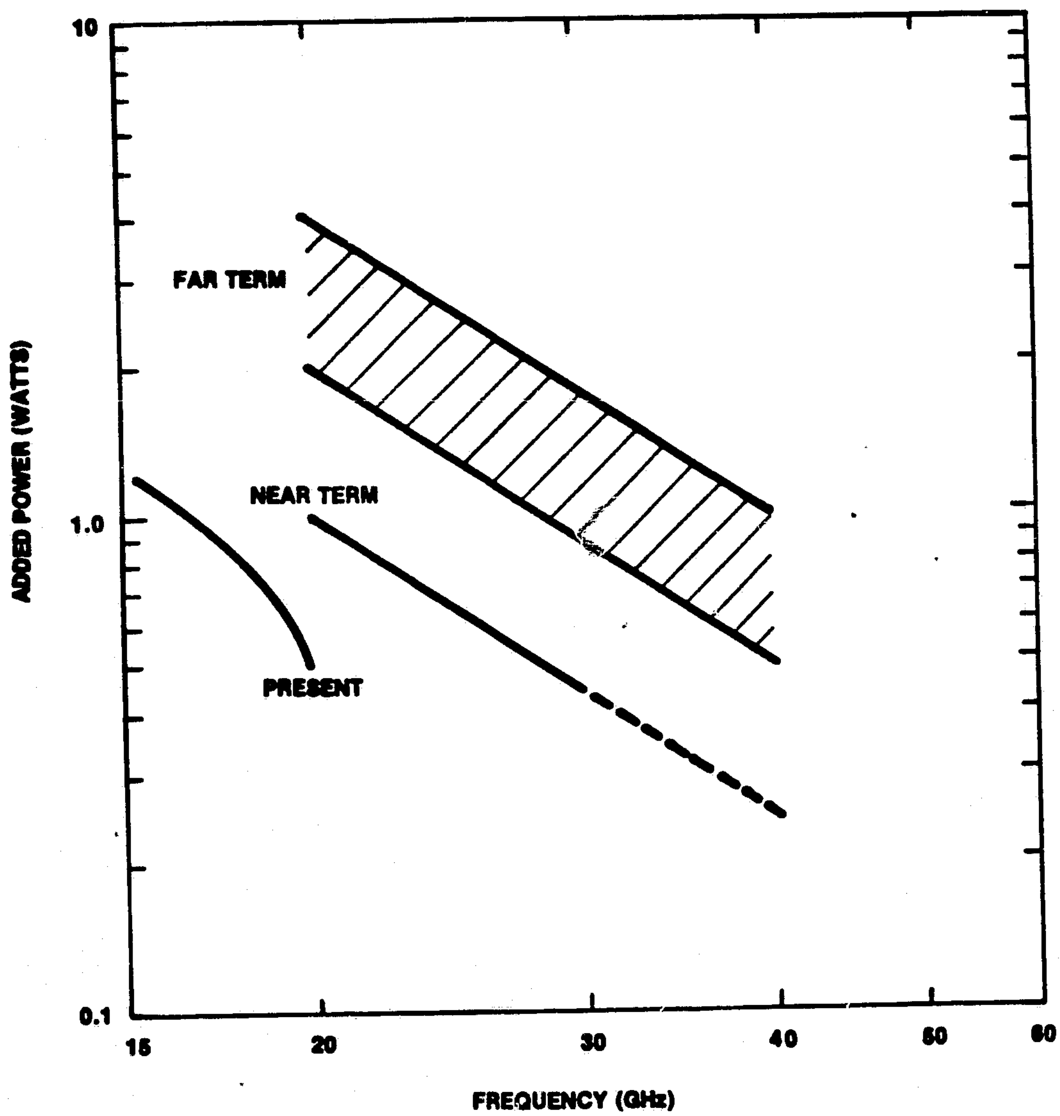


Figure 3.2-13. RF Power Output Projections: GaAs FETs

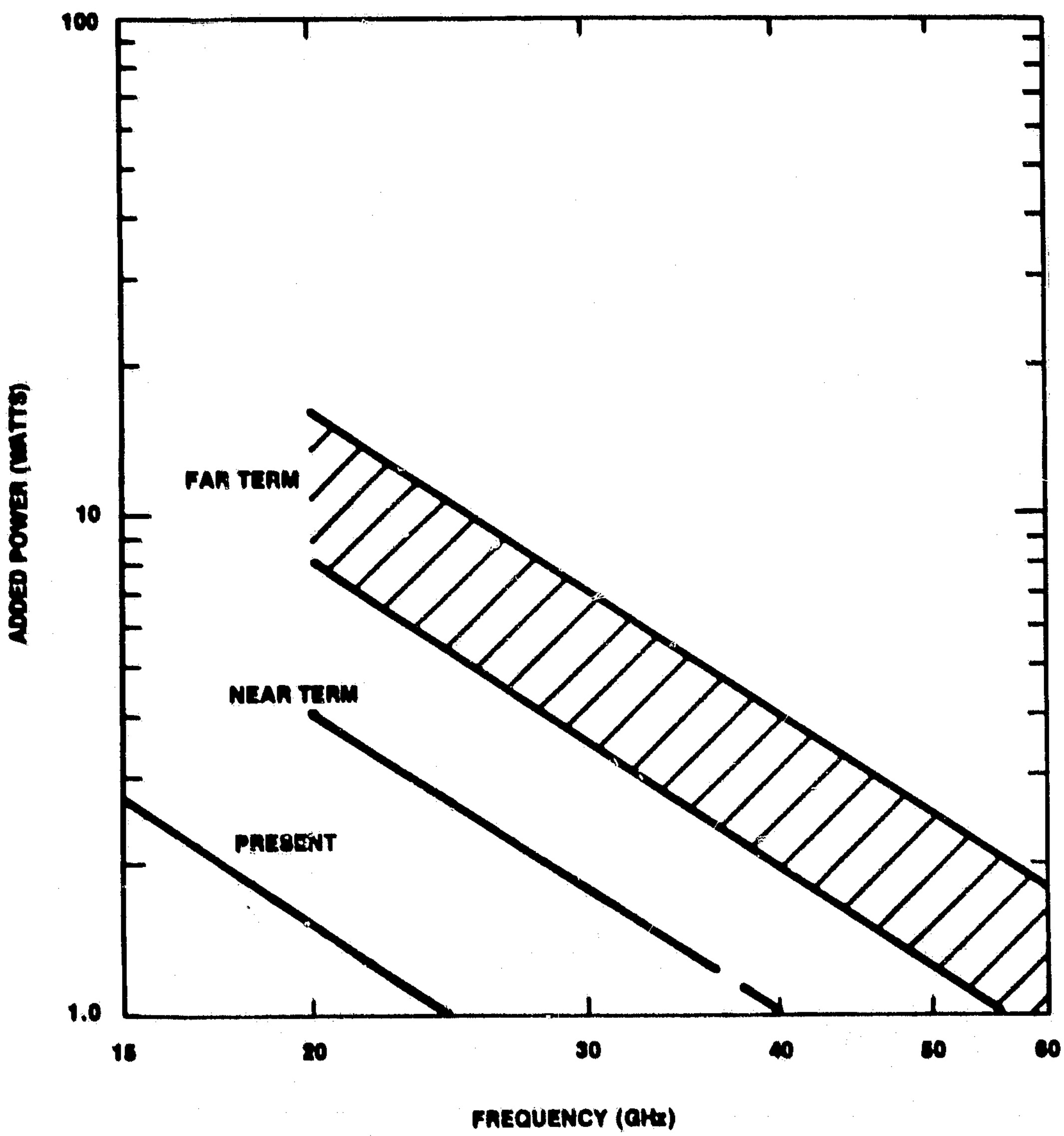


Figure 3.2-14. RF Power Output Projections: IMPATT Diodes

requirements are large due to the high peak power requirements of TDMA and the backoff in the HPA required for linear operation of a multichannel FDMA terminal.

The alternative which is called for by the CPS link requirements is one form of Traveling Wave Tube Amplifier. Development efforts at Ka band for Helix TWTAs were begun only five years ago. These amplifiers can only reliably support power outputs in the tens of watts range due to inefficient heat removal from the helix structure. Continued development efforts could produce higher output levels, particularly if design efforts are tailored towards pulsed operation for TDMA.

Coupled cavity TWTAs are predominantly used in the 30 to 100 GHz range. These HPAs can support hundreds of watts of RF power due to efficient heat removal. The significant cost driver is the fabrication of high precision components.

Low Noise Receiver

The crucial parameter, in LNA design is the noise temperature of the device. The gain of the amplifier is also a parameter but, assuming the gain is sufficiently large, the gain has little effect on overall C/N, the crucial link parameter. The links have been specified with 300°K LNA which is not realizable with today's technology. Incorporation of an uncooled GaAs FET LNA is crucial in terms of keeping the CPS station cost low. Table 3.2-4 is a comparison of low noise receiver technologies.

Frequency Converter

There are several design goals which must be met by the frequency converter. A single design which is compatible with all earth station concepts is desirable in the event that a hybrid payload concept is chosen. A single integrated unit for both up and down conversion is recommended to reduce costs. This allows the sharing of local oscillators in a two-stage converter (See Figure 3.2-15). This converter has a usable bandwidth of 300 MHz, which should be sufficient for all CPS applications. A thorough intermodulation analysis was performed to demonstrate the feasibility of the shared local oscillator concept. The choice of 1 GHz IF frequency is necessary to accommodate the 256 Mbps burst rate required for the scanning TDMA.

Table 3.2-4. Comparison of Receiver Front-End Approaches

TYPE	Predicted (1984) Receiver Noise Temperature	System Noise Temperature	Predicted (1990) Unit Cost	Predicted Development Cost (84-86)	MTBF
1. Broadband Mixer Plus Low-Noise IF Amp	1000K	1253K	$ 1,500	0	High
2. Image-enhanced Mixer Plus Low-Noise IF Amp	550K	785K	2,500	0	High
3. Cryogenically Cooled Image-enhanced Mixer Plus Low-Noise IF Amp	70K	305K	12,000	$100,000	Low
4. Uncooled Paramp	190K	425K	9,000	50,000	Moderate
5. Thermoelectrically Cooled Paramp	85K	320K	12,000	75,000	Moderate
6. Cryogenically Cooled Paramp	35K	270K	18,000	100,000	Low
7. FET Amplifier	300K	535K	1,000	50,000	High
8. Cryogenically Cooled FET	77K	312K	7,000	50,000	Low

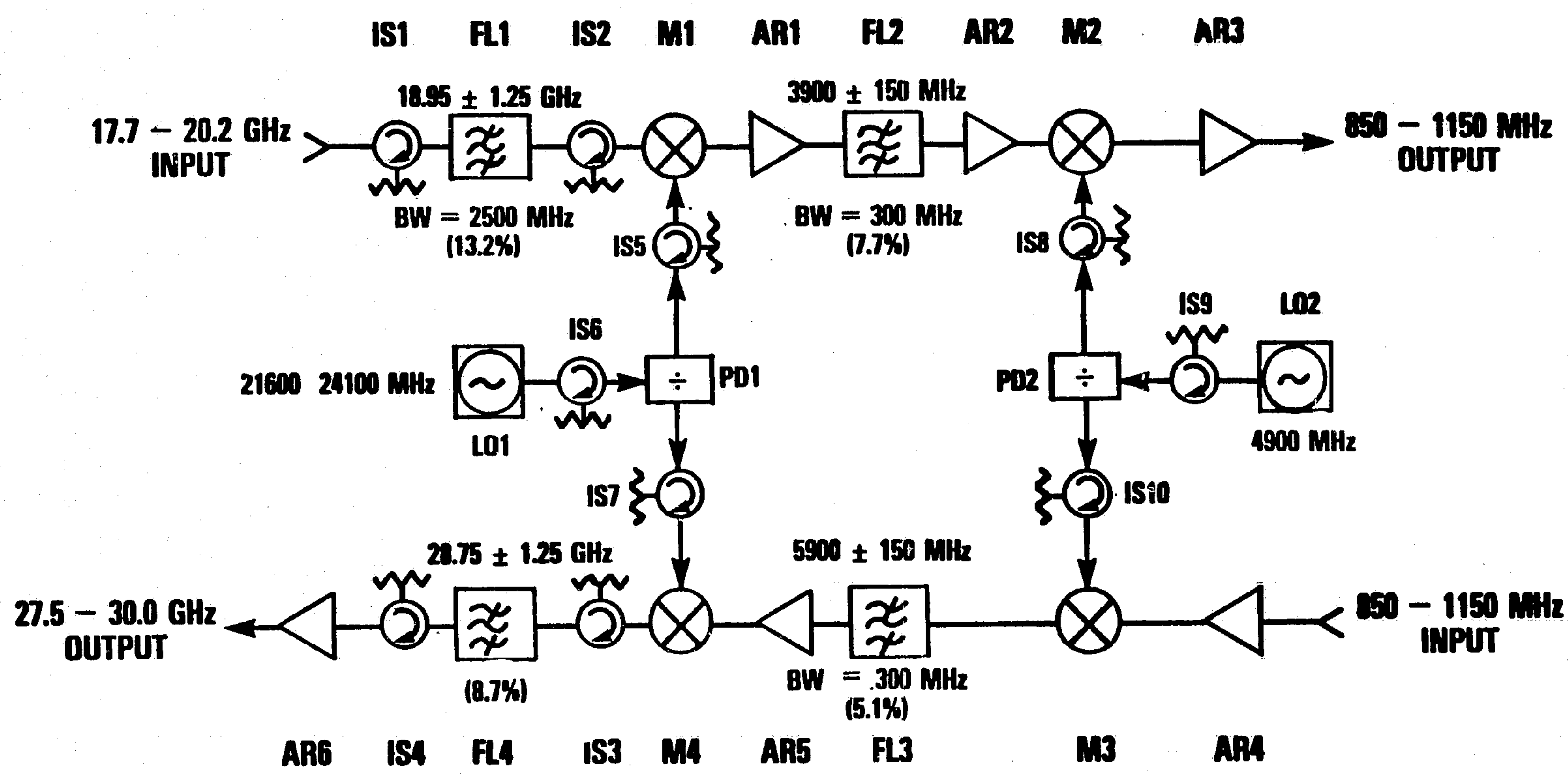


Figure 3.2-15. Frequency Converter Functional Block Diagram

3.2.6 LINK PERFORMANCE ANALYSIS

The link budgets to be discussed utilize the rain fade data based on the rain fade model developed by R.K. Crane as discussed by D.S. Frediani, "Technology Assessment of Future MIL SAT COM Systems: EHF Bands", MIT-LL Project Report DCA-5, April 1979. Figure 3.2-16 illustrates the fade statistics developed from the model and used in the budgets and the rain climate regions (zones) for which the statistics apply.

The attenuation distribution depends on the ES elevation angle. Those used in generating the graph, by zone, are B, 42^{o}; C, 32.5^{o}; D, 41^{o}; E, 54^{o}; and F, 44^{o}. These are the elevation angles from the mid-latitude and longitude of the zone.

The following factors are considered in the link budget and identified in Figure 3.2-17:

(1) P_{ES} = Earth station transmitter power per carrier

(2) L_{CE} = Earth station circuit losses

(3) G_{ET} = Gain of the earth station transmit antenna

= (Peak Gain) - (Pointing Losses) (dB)

(4) L_{CU} = Free space losses, uplink

$$= \frac{1}{4 \ \pi R^2} \cdot \frac{\lambda^2}{4\pi}$$

where λ is the wavelength of the carrier and R is the distance between the earth station and the satellite

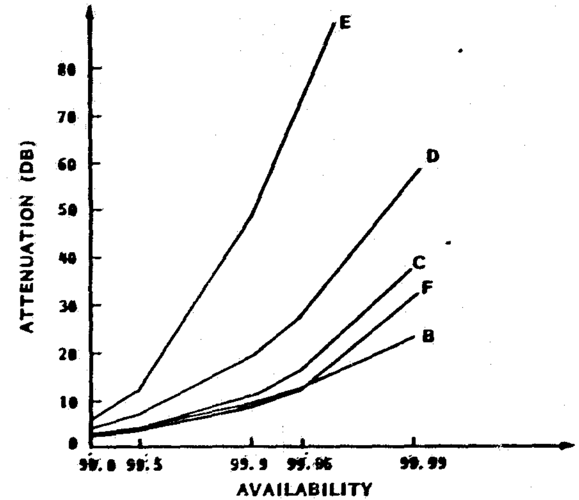
(5) L_{AU} = Atmospheric losses, uplink

(6) L_{RU} = Rain attenuation, uplink

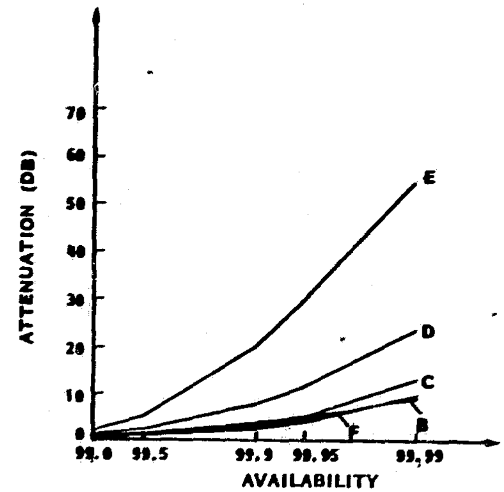
(7) G_{SR} = Gain of satellite receiving antenna -dB

= (Peak Gain) - (BFN Loses) - (Contour Loses) - (Circuit Loss)

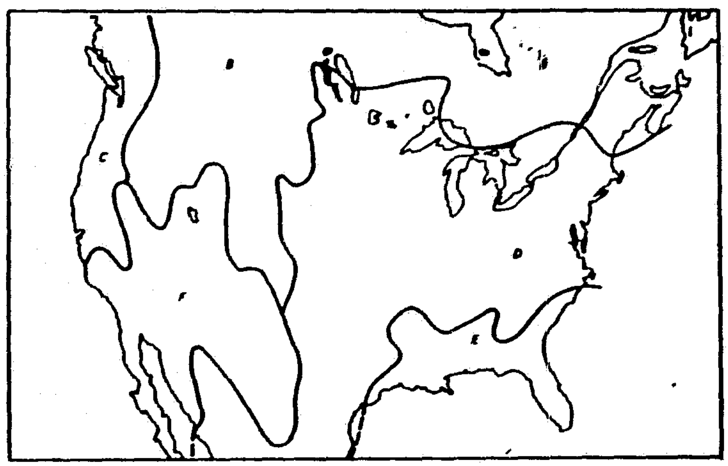
(8) I_{OS} = Interference power per unit bandwidth (watts/Hz) due to the adjacent channel and co-channel signals



UPLINK (F=30 GHz) ATTENUATION
VS. AVAILABILITY



DOWNLINK (F=20 GHz)ATTENUATON
VS. AVAILABILITY



RAIN CLIMATE REGIONS

Figure 3.2-16. Rain Fade Statistics

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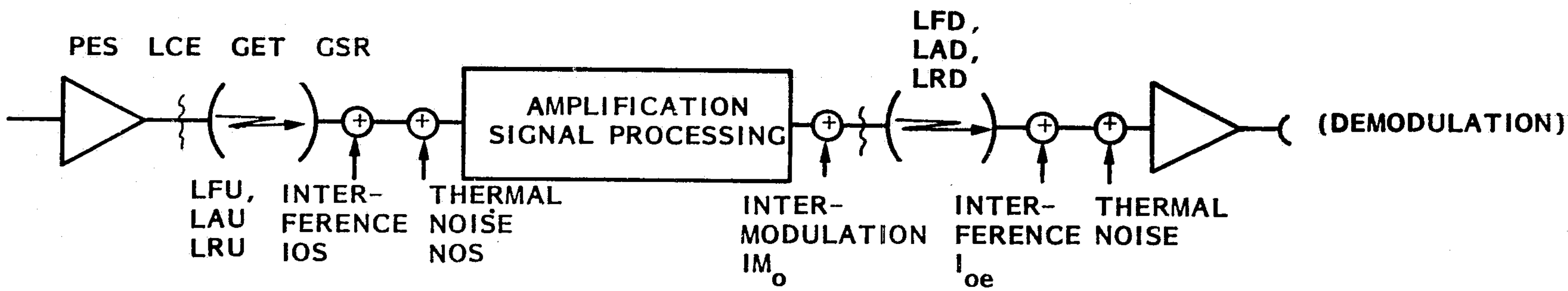

Figure 3.2-17. Satellite Communication Link

= $(\frac{C}{I_{OS}})^{-1} C$ (i.e., this is defined relative to the carrier power (C)).

(9) N_{OS} = Thermal noise per unit bandwidth.

(10) IM_0 = Intermodulation noise per unit bandwidth

= $(\frac{C}{IM_0})^{-1} C$

(11) L_{CS} = Circuit losses at the satellite

(12) G_{ST} = Gain of the satellite transmit antenna -dB

= (Peak Gain) - (BFN Losses) - (Contour Losses) - (Pointing loss)

(13) L_{FD}, L_{AD}, L_{RD} = Analogous to uplink losses

(14) G_{ER} = Gain of the earth station receiving antenna -dB

= (Peak Gain) - (Pointing Loss) - (Circuit Loss)

(15) I_{OE} = Interference power per unit bandwidth due to the adjacent channel and the co-channel signals

= $(\frac{C}{I_{OE}})^{-1} C$

(16) N_{OE} = Thermal noise at the earth station

All the factors except the rain attenuations L_{RU}, L_{RD}, the interferences I_{OS}, I_{OE}, and the intermodulation products IM_0 are treated as non-random degradations.

The links are designed so that in the nominal operating mode, i.e., 99% of the time, the up and down links are balanced, each contributes equally to the signal degradation.

All link budgets are normalized to an ES antenna diameter of 1 meter; a cell size of 1^o in width, which determines the normalized satellite antenna gain; a data rate of 1.54 Mbps; and in all cases the bit error rate is taken as 10^{-4}. For this BER the demodulation E_b/N_0 requirement is 11.4 dB based on a theoretical value of 8.4 dB plus 3 dB for the effects of carrier and clock jitter, intersymbol interference and implementation margins. The

normalized parameters are used so as to enable easy extrapolation of the data to a variety of other cases in the tradeoff analyses. The normalized link budgets do not represent a recommended operation configuration.

The up-link and the down-link, respectively, are assumed to have two adjacent channels and two co-channels which cause interference. The isolations between co-channels and adjacent channels are assumed to be 30 dB for SS-FDMA and SS-TDMA/Fixed Beam, and 40 dB for SS-TDMA/Scanning Beam. The required increase of the carrier power due to interference is determined by obtaining the statistical worst carrier-to-interference ratio for the desired link availability, which is converted to the required carrier-to-noise ratio increase through the use of Figure 3.2-18 (four-interferer curve). The link budgets are illustrated in Tables 3.2-5 through 3.2-10 which are all for 99.5% availability in rain zone D and are normalized based on the parameters defined above.

The link budgets illustrate the conditions that obtain for the link design under Quiescent conditions, no fading, and uplink or downlink fades. Not shown are the case of fading in both links simultaneously but the links are designed to support that case also. Earth station and satellite transmit power per carrier for other data rates, antenna sizes, and cell sizes can be obtained from, for FDMA:

$$P_T = P_{TN} + 20 \log \alpha - 20 \log D + KD^2 + 10 \log (DR/1.54) \quad \text{dB}$$

For TDMA the peak power is

$$P_T = P_{TN} + 20 \log \alpha - 20 \log D + KD^2 + 10 \log (DR/1.54) + 10 \log (BR/1.54) \quad \text{(dB)}$$

where: P_T = Peak transmit power; P_{TN} = Normalized power from link budgets; α = Cell width in degrees as seen from satellite; D = ES Antenna diameter in meters; K = ES pointing factor = 0.21 Earth Station Transmitting ($D < 2M$), = 0.09 Satellite Transmitting ($D < 2M$), = 0.0, $D < 2M$; DR = Average data rate in Mbps; BR = Burst rate in Mbps.

SS-FDMA

In the FDMA case, rain fading is compensated by an increase in the ES transmit power to compensate an uplink fade or to cause an increased satellite transmit

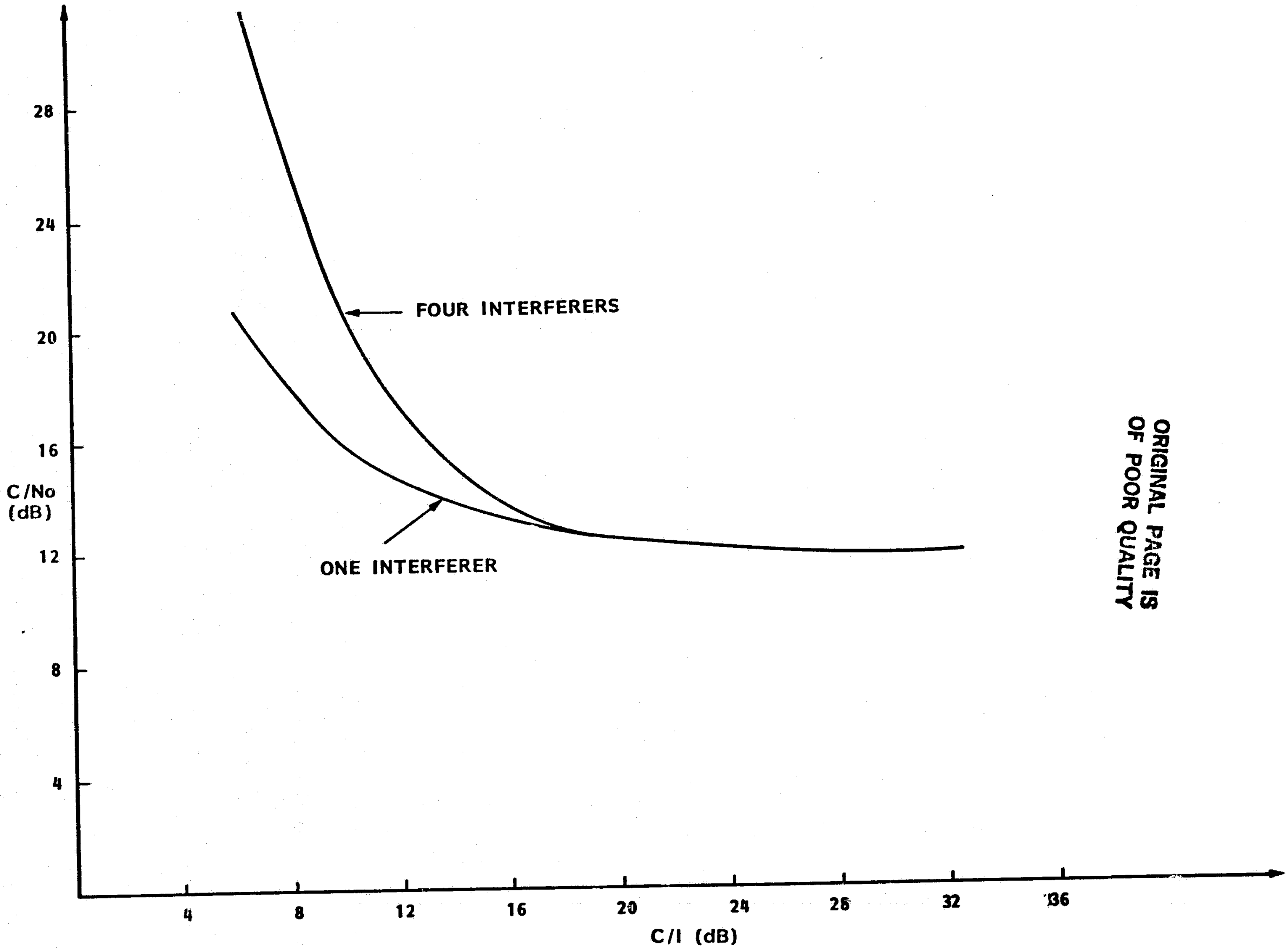

Figure 3.2-18. Interference Degradation

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Table 3.2-5. SS-FDMA Uplink Budget 99.5% Availability - Rain Zone D

		QUIESCENT	UPLINK FADE
CARRIER-TO-(NOISE + INTERFERENCE + IM) AT ES RECEIVER	$(\frac{C}{X_o})_s$	73.3	73.3 dB
DOWNLINK DEGRADATION	D	3.0	3.6 dB
UPLINK $\frac{C}{X_o}$ REQUIRED	$(\frac{C}{X_o})_u$	76.3	76.9 dB
UPLINK $\frac{C}{X_o}$ DEGRADATION DUE TO INTERFERENCE	ID	1.4	1.4 dB
UPLINK $\frac{C}{N_o}$ REQUIRED	$(\frac{C}{N_o})_u$	77.7	78.3 dB
EARTH STATION CIRCUIT LOSSES	L_{CE}	1.5	1.5 dB
FREE SPACE LOSS	L_{FU}	213.3	213.3 dB
ATMOSPHERIC LOSS	L_{AU}	0.6	9.0 dB
GAIN OF SATELLITE RECEIVE ANTENNA ($\alpha = 1$)	G_{SR}	(39.2)	(39.2) dBi
UPLINK MARGIN	M_u	6.0	0.0 dB
SATELLITE RECEIVE NOISE TEMPERATURES	T_S	30.1	30.1 dB°K
BOLTZMANN'S CONSTANT	K	-228.6	-228.6 dBw/Hz/°K
ES EIRP REQUIRED	$EIRP_{ES}$	61.4	64.4 dBw
ES ANTENNA GAIN (D = 1)	G_{ET}	(46.5)	(46.5) dBi
ES POWER	P_{ES}	14.9	17.9 dBw

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Table 3.2-6. SS-FDMA Downlink Budget 99.5% Availability - Rain Zone D

		QUIESCENT	DOWNLINK FADE
CARRIER-TO-(NOISE + INTERFERENCE + IM) AT ES RECEIVER	$(\frac{C}{X_o})_s$	73.3	73.3 dB
UPLINK DEGRADATION	$\frac{D}{D-1}$	3.0	2.1 dB
DOWNLINK $\frac{C}{X_o}$ REQUIRED	$(\frac{C}{X_o})_d$	76.3	75.4 dB
DOWNLINK DEGRADATION DUE TO INTERFERENCE		1.4	1.4 dB
DOWNLINK $\frac{C}{N_o}$ REQUIRED	$(\frac{C}{N_o})_d$	77.9	76.8 dB
SATELLITE CIRCUIT LOSS	L_{es}	1.0	1.0 dB
FREE SPACE LOSS	L_{FD}	209.7	209.7 dB
ATMOSPHERIC LOSS	L_{AD}	0.5	8.5 dB
GAIN OF ES RECEIVE ANTENNA (D=1)	G_{ER}	(43.0)	(43.0) dBi
DOWNLINK MARGIN	M_d	6.0	0.1 dB
EARTH STATION NOISE TEMPERATURE	T_{ES}	28.4	28.4 dB°K
BOLTZMANN'S CONSTANT	K	-228.6	-228.6 dBw/Hz/°K
SATELLITE EIRP REQUIRED	$EIRP_s$	51.7	52.9 dBw
SATELLITE ANTENNA GAIN ($\alpha = 1$)	G_{ST}	(39.2)	(39.2) dBi
SATELLITE POWER		12.5	13.7 dBw

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Table 3.2-7. SS-TDMA/Fixed Beam Uplink Budget 99.5% Availability - Rain Zone D

		QUIESCENT	UPLINK FADE	
CARRIER-TO-(NOISE + INTERFERENCE + IM) AT ES RECEIVER	$(\frac{C}{X_o})_s$	73.3	65.9	dB
DOWNLINK DEGRADATION	D	3.0	0.4	dB
UPLINK $\frac{C}{X_o}$ REQUIRED	$(\frac{C}{X_o})_u$	76.3	66.3	dB
UPLINK $\frac{C}{X_o}$ DEGRADATION DUE TO INTERFERENCE	ID	0.6	0.6	dB
UPLINK $\frac{C}{N_o}$ REQUIRED	$(\frac{C}{N_o})_u$	76.9	66.9	dB
EARTH STATION CIRCUIT LOSSES	L_{CE}	1.5	1.5	dB
FREE SPACE LOSS	L_{FU}	213.3	213.3	dB
ATMOSPHERIC LOSS	L_{AU}	0.6	9.0	dB
GAIN OF SATELLITE RECEIVE ANTENNA (α =1)	G_{SR}	(39.2)	(39.2)	dBi
UPLINK MARGIN	M_u	4.5	3.1	dB
SATELLITE RECEIVE NOISE TEMPERATURES	T_S	30.1	30.1	dB°K
BOLTZMANN'S CONSTANT	K	-228.6	-228.6	dBw/Hz°K
ES EIRP REQUIRED	$EIRP_{ES}$	59.1	56.1	dBw
ES ANTENNA GAIN (D=1)	G_{ET}	(46.5)	(46.5)	dBi
ES POWER	P_{ES}	12.6	9.6	dBw

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Table 3.2-8. SS-TDMA/Fixed Beam Downlink Budget 99.5% Availability - Rain Zone D

		QUIESCENT	DOWNLINK FADE
CARRIER-TO-(NOISE + INTERFERENCE + IM) AT ES RECEIVER	$(\frac{C}{X_o})_s$	73.3	65.9 dB
UPLINK DEGRADATION	$\frac{D}{D-1}$	3.0	0.4 dB
DOWNLINK $\frac{C}{X_o}$ REQUIRED	$(\frac{C}{X_o})_d$	76.3	66.3 dB
DOWNLINK DEGRADATION DUE TO INTERFERENCE		2.4	2.4 dB
DOWNLINK $\frac{C}{N_o}$ REQUIRED	$(\frac{C}{N_o})_d$	79.1	69.1 dB
SATELLITE CIRCUIT LOSS	L_{ES}	1.0	1.0 dB
FREE SPACE LOSS	L_{FD}	209.7	209.7 dB
ATMOSPHERIC LOSS	L_{AD}	0.5	8.5 dB
GAIN OF ES RECEIVE ANTENNA (D=1)	G_{ER}	(43.0)	(43.0) dBi
DOWNLINK MARGIN	M_d	2.0	4.0 dB
EARTH STATION NOISE TEMPERATURE	T_{ES}	28.4	28.4 dB°K
BOLTZMANN'S CONSTANT	K	-228.6	-228.6 dBw/Hz/°K
SATELLITE EIRP REQUIRED	$EIRP_s$	48.7	48.7 dBw
SATELLITE ANTENNA GAIN (α=1)	G_{ST}	(39.2)	(39.2) dBi
SATELLITE POWER		9.5	9.5 dBw

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Table 3.2-9. SS-TDMA/Scanning Beam Uplink Budget 99.5% Availability - Rain Zone D

		QUIESCENT	UPLINK FADE
CARRIER-TO-(NOISE + INTERFERENCE + IM) AT ES RECEIVER	$(\frac{C}{X_o})_s$	73.7	66.3 dB
DOWNLINK DEGRADATION	D	0.0	0.0 dB
UPLINK $\frac{C}{X_o}$ REQUIRED	$(\frac{C}{X_o})_u$	73.7	66.3 dB
UPLINK $\frac{C}{X_o}$ DEGRADATION DUE TO INTERFERENCE	ID	0.3	0.3 dB
UPLINK $\frac{C}{N_o}$ REQUIRED	$(\frac{C}{N_o})_u$	74.0	66.6 dB
EARTH STATION CIRCUIT LOSSES	L_{CE}	1.5	1.5 dB
FREE SPACE LOSS	L_{FU}	213.3	231.3 dB
ATMOSPHERIC LOSS	L_{AU}	0.6	9.0 dB
GAIN OF SATELLITE RECEIVE ANTENNA ($\alpha = 1^o$)	G_{SR}	(39.2)	(39.2) dBi
UPLINK MARGIN	M_u	4.5	3.5 dB
SATELLITE RECEIVE NOISE TEMPERATURES	T_S	30.1	30.1 dB°K
BOLTZMANN'S CONSTANT	K	-228.6	-228.6 dBw/Hz/°K
ES EIRP REQUIRED	$EIRP_{ES}$	56.2	56.2 dBw
ES ANTENNA GAIN (D=1)	G_{ET}	(46.5)	(46.5) dBi
ES POWER	P_{ES}	9.7	9.7 dBw

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Table 3.2-10. SS-TDMA/Scanning Beam Downlink Budget 99.5% Availability - Rain Zone D

		QUIESCENT	DOWNLINK FADE	
CARRIER-TO-(NOISE + INTERFERENCE + IM) AT ES RECEIVER	$(\frac{C}{X_o})_s$	73.7	66.3	dB
UPLINK DEGRADATION	$\frac{D}{D-1}$	0.0	0.0	dB
DOWNLINK $\frac{C}{X_o}$ REQUIRED	$(\frac{C}{X_o})_d$	73.7	66.3	dB
DOWNLINK DEGRADATION DUE TO INTERFERENCE		2.3	2.3	dB
DOWNLINK $\frac{C}{N_o}$ REQUIRED	$(\frac{C}{N_o})_d$	76.0	68.6	dB
SATELLITE CIRCUIT LOSS	L_{ES}	1.0	1.0	dB
FREE SPACE LOSS	L_{FD}	209.7	209.7	dB
ATMOSPHERIC LOSS	L_{AD}	0.5	8.5	dB
GAIN OF ES RECEIVE ANTENNA (D=1)	G_{ER}	(43.0)	(43.0)	dBi
DOWNLINK MARGIN	M_D	2.0	1.4	dB
EARTH STATION NOISE TEMPERATURE	T_{ES}	28.4	28.4	dB°K
BOLTZMANN'S CONSTANT	K	-228.6	-228.6	dBw/Hz/°K
SATELLITE EIRP REQUIRED	$EIRP_s$	46.0	46.0	dBw
SATELLITE ANTENNA GAIN (α =1)	G_{ST}	(39.2)	(39.2)	dBi
SATELLITE POWER		6.8	6.8	dBw

power for the case of downlink fade. To avoid frequent changes in transmit power the required fade margin is divided into a fixed part which compensates for fades 99% of the time and a variable part to compensate the remainder required to achieve the desired availability.

Figure 3.2-19 illustrates a SS-FDMA link, intermodulation interference and the adjacent channel and co-channel interference are not shown.

The CNR at the receiver station is given as

$$CNR = \left(\frac{N_{OS}\, L_{RU}}{C} + \frac{N_{OE}\, L_{RU}\, L_{RD}}{G_1\, G_2\, C}\right)^{-1}$$

The required power margins are determined in such a manner that

$$PR\left\{CNR \geqslant (CNR)_{req}\right\}$$

exceeds the desired availability. The maximum and fixed power margins are summarized in Table 3.2-11.

The expected maximum increase of the input power to the transponder is obtained through the analysis of the probabilistic behavior of the transmitter power of the earth station governed by rain attenuation. The TWT input/output back-off level is determined by the expected maximum input power increase and the TWT performance characteristic. The satellite transponder back-off levels are presented in Table 3.2-11.

In Tables 3.2-5 and 3.2-6, two cases are shown, a Quiescent case which reflects the requirements for operation 99% of the time and a Faded case which shows the changes needed to achieve the desired availability, 99.5% in the case shown.

Note that the budgets are normalized as discussed previously.

A noteworthy point is that the fixed margins can be shared in the FDMA case between the up and downlinks so that fade compensation does not require as large a variation in power levels as would be intuitively expected.

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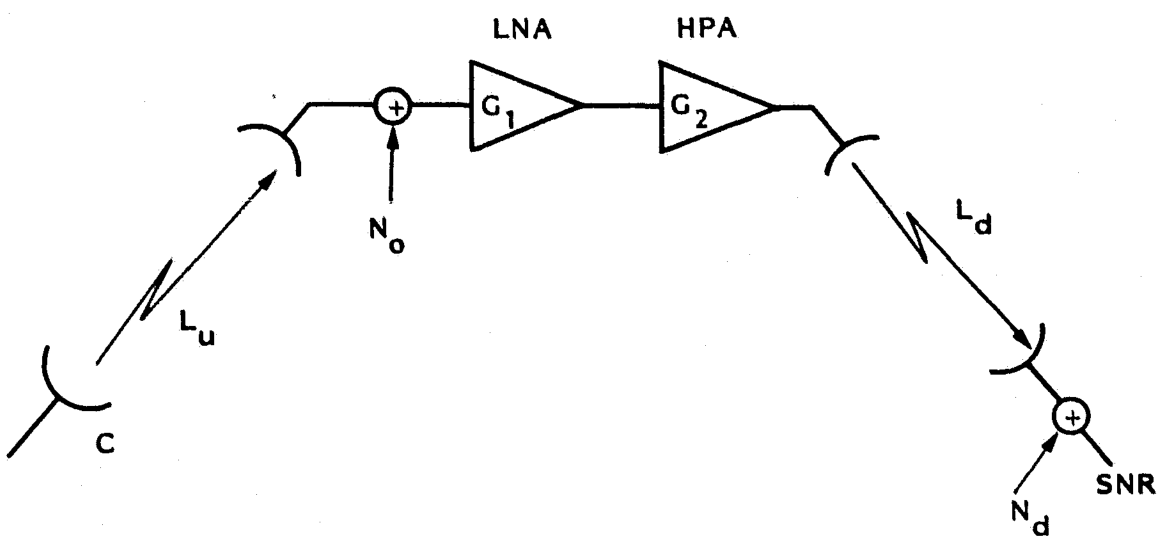

C	:	THE POWER OF THE TRANSMITTED CARRIER
L_{RU}	:	THE RAIN LOSS OF THE UP-LINK
N_u	:	THE UP-LINK THERMAL NOISE
G_1, G_2	:	THE GAINS OF THE AMPLIFIERS
L_{RD}	:	THE RAIN LOSS OF THE DOWN-LINK
N_d	:	THE DOWN-LINK THERMAL NOISE

Figure 3.2-19. Link Factors, SS-FDMA

Table 3.2-11. Link Budget (SS-FDMA)

Availability %	Zone	Uplink			Downlink				Unexcited TWT Output B.O.
		Fixed	Variable	DC/I*	Fixed	Variable	DC/I*	DIM**	
99.5	B	3.0	3.0	1.0	3.0	3.0	1.0	1.0	6.8
	C	3.0	4.0	1.0	3.0	4.0	1.0	1.0	6.8
	D	6.0	6.0	1.4	6.0	6.0	1.4	1.0	6.2
	E	10.5	15.0	10.6	10.5	15.0	10.6	1.0	6.5
	F	3.0	4.5	1.0	3.0	4.5	1.0	1.0	6.8
99.9	B	3.0	8.5	1.3	3.0	8.5	1.3	1.0	6.8
	C	3.0	11.0	1.3	3.0	11.0	1.3	1.0	7.2
	D	6.0	18.5	4.4	6.0	18.5	4.4	1.0	6.6
	E	10.5	50.0	---	10.5	50.0	---	1.0	36.0
	F	3.0	11.0	1.3	3.0	11.0	1.3	1.0	7.2
99.95	B	3.0	12.0	3.6	3.0	12.0	3.6	1.0	8.0
	C	3.0	15.0	3.6	3.0	15.0	3.6	1.0	10.2
	D	6.0	25.5	16.5	6.0	25.5	3.6	1.0	7.2
	E	10.5	70.5	---	10.5	70.5	----	1.0	56.5
	F	3.0	14.5	3.6	3.0	14.5	3.6	1.0	9.8

* DC/CI: The required power increase due to interference.
** DIM: The required power increase due to IM$\geq$18.5 (dB)
---: Power requiement exceeds a practically reasonable power increase
•: Adjacent and co-channel isolation = 30 (dB)

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SS-TDMA/Fixed Beam

This system employs a nondemodulating, IF switched transponder with fixed drive to the power amplifiers. This scheme is based on fixed plus variable transmitter peak power per carrier at the earth station and fixed transmitter peak power at the satellite. The fixed and variable margin at the earth station is employed to reduce the co-channel and adjacent channel interference.

The power margins for the up and down links are determined in such a manner that

$$P_r \left\{ \left[L_{RU} \left(\frac{C}{X_0}^{-1}\right)_U + L_{RD} \left(\frac{C}{X_0}^{-1}\right)_D \right] \leqslant \left(\frac{C}{X_0}^{-1}\right)_{Req.} \right\}$$

exceeds the desired link availability. The fixed and variable margins are summarized in Table 3.2-12.

Rain fade compensation is by means of fixed plus variable margins and forward error correction coding R = 1/2, constraint length 5, soft decision, which permits a 4.4 dB reduction in Eb/No. The 2:1 reduction in data rate associated with FEC permits a 3 dB reduction in carrier power. In combination a 7.4 dB margin is provided by the use of FEC. This margin is assumed to be used totally or not at all which contributes to the additional margins shown in the budgets due to overcompensation of the fade. (Tables 3.2-7, 3.2-8).

Like the SS-FDMA case, the up and downlink margins can be shared resulting, here, in additional margins above those required by the downlink fades experienced less than 99.5% of the time.

SS-TDMA/Scanning Beam

Rain fade compensation of this scheme is by means of FEC and fixed plus variable margins as in the SS-TDMA/Fixed Beam case. The fixed plus variable margins are employed to reduce the co-channel and adjacent channel interference. The up and down-link margins M_u and M_d are determined in such a manner that

$P_r \left[L_{RU} \leqslant M_u, L_{RD} \leqslant M_d \right]$ exceeds the desired availability.

Table 3.2-12. Link Budgets (SS-TDMA, Fixed Beam)

		Uplink				Downlink			
Availability	Zone	Fixed Margins	Variable Margins	Coding Gain	DC/I*	Fixed Margins	Coding Gain	DIM**	DC/I*
99.5	B	2.0	0.0	7.4	0.6	1.0	7.4	2.0	0.4
	C	2.5	0.0	7.4	0.6	1.0	7.4	2.0	0.4
	D	4.5	0.0	7.4	0.8	2.0	7.4	2.0	0.4
	E	11.1	0.0	7.4	4.3	9.6	7.4	2.0	0.4
	F	2.5	0.0	7.4	0.6	1.0	7.4	2.0	0.4
99.9	B	2.0	0.0	7.4	016	1.0	7.4	2.0	0.4
	C	2.5	0.0	7.4	0.6	1.0	7.4	2.0	0.4
	D	4.5	8.1	7.4	0.8	6.6	7.4	2.0	0.4
	E	11.1	32.0	7.4	4.3	32.6	7.4	2.0	0.4
	F	2.5	0.0	7.4	0.6	1.0	7.4	2.0	0.4
99.95	B	2.0	2.6	7.4	0.6	3.1	7.4	2.0	0.4
	C	2.5	5.1	7.4	0.6	3.1	7.4	2.0	0.4
	D	4.5	16.1	7.4	0.8	14.6	7.4	2.0	0.4
	E	11.1	56.5	7.4	4.3	57.6	7.4	2.0	0.4
	F	2.5	2.1	7.4	0.6	3.1	7.4	2.0	0.4

* DC/I: The required power increase due to interference
** DIM: The required power increase due to IM = 17 (dB)
• Adjacent and co-channel isolation - 30 (dB)

The transponder in the scanning beam antenna system employs demodulators and baseband switching which decouples the up and downlinks preventing the accumulation of noise but resulting in the addition of bit errors. Compensation for the bit error addition is by halving the BER on each link which increases the required power by 0.4 dB.

The downlink, being decoupled from the uplink, presents a isolated link the operation and design of which is approximately independent of uplink. However, there is a tradeoff possible between up and downlink availability, keeping the end-to-end availability constant, that influences the ES and transponder power requirement. The design shown is based on increasing the downlink availability to relieve the ES power requirement.

The fixed and variable power margins are summerized in Table 3.2-13. Tables 3.2-9 and 3.2-10 are for 99.5% availability in rain zone D.

Station Diversity

It is assumed that two earth stations are available for one channel and the stations are separated sufficiently such that the rain attenuation at the earth stations can be assumed statistically independent. In order to avoid frequent switching between stations, fixed margins are provided in the link budget. The 99% fixed margins obtained in Sections 3.2.6 to 3.2.8 can be shown to attain 99.99% availability for SS-FDMA, SS-TDMA/Fixed Beam and Scanning Beam cases.

Summary - EIRP Requirements

Tables 3.2-14 to 3.2-19 summarize the link budget analyses and include results for availabilities from 99.5% to 99.95% and the various rain-zones found in the CONUS rain climate regions (Figure 3.2-16). The EIRP's listed apply to ES having an antenna diameter of 1 m and a satellite antenna providing cell sizes 1^{o} wide. The data can be scaled to other antenna and cell sizes.

In Tables 3.2-14 to 3.2-17, the isolation of the adjacent channel and co-channel is assumed to be 30 (dB) for FDMA and TDMA/Fixed Beam, and 40 (dB) for TDMA/Scanning Beam. Tables 3.2-16 and 3.2-17 show EIRP requirements when station diversity operation is employed, while Table 3.2-14 and 3.2-15 present EIRP requirements without station diversity operation. In Tables 3.2-14 and 3.2-16, average EIRP's are shown for the case of a single 1.54 Mbps carrier

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Table 3.2-13. Link Budgets (SS-TDMA, Scanning Beam)

Avail.	Zone	Uplink Fixed Margins	Uplink Variable Margins	Uplink Coding Gain	Uplink DC/I *	Downlink Fixed Margin	Downlink Coding Gain	Downlink DIM**	Downlink DC/I*
99.5	B	2.5	0.0	7.4	0.3	2.0	7.4	2.0	0.3
	C	3.0	0.0	7.4	0.3	2.0	7.4	2.0	0.3
	D	6.0	0.0	7.4	0.3	4.5	7.4	2.0	0.3
	E	11.1	0.0	7.4	0.3	9.6	7.4	2.0	0.3
	F	3.5	0.0	7.4	0.3	2.0	7.4	2.0	0.3
99.9	B	2.5	0.0	7.4	0.3	2.0	7.4	2.0	0.3
	C	4.1	1.1	7.4	0.3	2.6	7.4	2.0	0.3
	D	14.6	8.6	7.4	0.3	8.1	7.4	2.0	0.3
	E	46.1	35.0	7.4	0.3	35.1	7.4	2.0	0.3
	F	3.5	0.0	7.4	0.3	2.0	7.4	2.0	0.3
99.95	B	7.1	4.6	7.4	0.3	4.6	7.4	2.0	0.3
	C	10.1	7.1	7.4	0.3	3.1	7.4	2.0	0.3
	D	24.6	18.6	7.4	0.3	16.1	7.4	2.0	0.3
	E	67.6	56.5	7.4	0.3	57.6	7.4	2.0	0.3
	F	7.1	3.6	7.4	0.3	5.6	7.4	2.0	0.3

* DC/I: The required power increase due to interferance
** DIM: The required power increase due to IM = 17 (dB)
• channel isolation = 40 (dB)

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Table 3.2-14. Earth Station and Satellite Average EIRP Requirements

System	Rain Zone	Earth Station Availability %			Satellite Availability %		
		49.5	99.9	99.95	99.5	99.9	99.95
FDMA	C(B,F)	62.0	69.3	75.6	50.0	54.1	56.8
	D	66.6	83.1	102.2	54.0	60.9	82.0
	E	90.2	---	---	70.4	---	---
TDMA Fixed Beam	C(B,F)	57.1	57.1	62.2	47.7	47.7	49.8
	D	59.3	67.4	75.4	48.7	53.3	61.3
	E	69.4	101.4	125.9	56.3	79.3	104.3
TDMA Scanning Beam	C(B,F)	54.7	55.8	61.8	46.0	46.6	47.1
	D	57.7	66.3	76.3	48.5	52.1	60.1
	E	62.8	97.8	119.3	53.6	79.1	101.6

---: Unable to attain the desired availability with 30 (dB) interference isolation

Conditions

- 1 M ES Antenna
- 1° Cell Diameter
- 1.54 MBPS Peak and average data rate
- Adjacent and co-channel isolation:
  FDMA, TDMA/Fixed Beam = 30 (dB)
  TDMA/Scanned Beam = 40 (dB)

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Table 3.2-15. Earth Station and Satellite Peak EIRP Requirements

System	Rain Zone	Earth Station Availability % 99.5	99.9	99.95	Satellite Availability % 99.5	99.9	99.95
FDMA	C(B,F)	62.0	69.3	75.6	68.5	72.6	75.3
	D	66.6	83.1	102.2	72.5	79.4	100.4
	E	90.1	---	---	---	---	---
TDMA Fixed Beam	C(B,F)	69.6	69.6	74.7	60.2	60.2	62.3
	D	71.8	79.9	87.9	61.2	65.8	73.8
	E	81.9	113.9	138.4	68.8	86.8	116.8
TDMA Scanning Beam	C(B,F)	67.2	68.3	74.3	58.5	59.1	59.6
	D	70.2	78.8	88.8	61.0	64.6	72.1
	E	75.3	110.3	131.8	66.1	91.6	114.1

---: Unable to attain the desired availability with 30 dB interference isolation.

Conditions
- 1 M ES Antenna
- 1° Cell Diameter
- 1.54 MBPS Average ES Data Rate
- 27.5 MBPS through the transponder
- Adjacent and co-channel isolation:
  FDMA, TDMA/Fixed Beam = 30 dB
  TDMA/Scanned Beam = 40 dB

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Table 3.2-16. Earth Station and Satellite Average EIRP Requirement (Station Diversity)

System	Rain Zone	Earth Station Availability %			Satellite Availability %		
		99.5	99.9	99.95	99.5	99.9	99.95
FDMA	C(B,F)	58.0	58.0	58.0	46.0	46.0	46.0
	D	60.6	60.6	60.6	48.0	48.0	48.0
	E	76.8	76.8	76.8	57.1	57.1	57.1
TDMA Fixed Beam	C(B,F)	57.1	57.1	57.1	47.7	47.7	47.7
	D	59.3	59.3	59.3	48.7	48.7	48.7
	E	69.4	69.4	69.4	56.3	56.3	56.3
TDMA Scanning Beam	C(B,F)	54.7	54.7	54.7	46.0	46.0	46.0
	D	57.7	57.7	57.7	48.5	48.5	48.5
	E	62.8	62.8	62.8	53.6	53.6	53.6

Conditions
- Two ES Diversity
- 1 M ES Antenna
- 1^{o} Cell Diameter
- 1.54 MBPS Peak and average data rate
- Adjacent and co-channel isolation:
  FDMA,TDMA/Fixed Beam = 30 dB
  TDMA/Scanned Beam = 40 dB

Table 3.2-17. Earth and Satellite Peak EIRP Requirements (Station Diversity)

System	Rain Zone	Earth Station Availability %			Satellite Availability %		
		99.5	99.9	99.95	99.5	99.9	99.95
FDMA	C(B,F)	58.0	58.0	58.0	64.5	64.5	64.5
	D	60.6	60.6	60.6	67.5	67.5	67.5
	E	76.8	76.8	76.8	75.6	75.6	75.6
TDMA Fixed Beam	C(B,F)	69.6	69.6	69.6	60.2	60.2	60.2
	D	71.8	71.8	71.8	61.2	61.2	61.2
	E	81.9	81.9	81.9	68.8	68.8	68.8
TDMA Scanning Beam	C(B,F)	67.2	67.2	67.2	58.5	58.5	58.5
	D	70.2	70.2	70.2	61.0	61.0	61.0
	E	75.3	75.3	75.3	66.1	66.1	66.1

Conditions

- 1 M ES Antenna
- 1° Cell Diameter
- 1.54 MBPS Average ES Data Rate
- 27.5 MBPS TDMA ES Burst Rate
- 27.5 MBPS Through the transponder
- Adjacent and co-channel isolation:
  FDMA, TDMA/Fixed Beam = 30 dB
  TDMA/Scanned Beam = 40 dB

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Table 3.2-18. Earth Station and Satellite Average EIRP Requirements

System	Rain Zone	Earth Station Availability %			Satellite Availability		
		99.5	99.9	99.95	99.5	99.9	99.95
FDMA	C(B,F)	66.4	74.2	85.6	54.4	59.0	66.8
	D	75.2	89.4	---	61.6	67.2	---
	E	---	---	---	---	---	---
TDMA Fixed Beam	C(B,F)	58.3	58.3	63.4	47.7	47.7	49.8
	D	60.7	68.8	76.8	48.7	53.3	61.3
	E	77.9	109.9	134.4	56.3	79.3	104.3
TDMA Scanning Beam	C(B,F)	54.7	55.8	61.8	46.0	46.6	47.1
	D	57.7	60.3	76.3	48.5	52.1	60.1
	E	62.8	97.8	119.3	53.6	79.1	101.6

---: Unable to attain the availability with 25 dB interference isolation

Conditions

- 1 M ES Antenna
- 1^{o} Cell Diameter
- 1.54 MBPS peak and average data rate
- Adjacent and co-channel isolation:
  FDMA, TDMA/Fixed Beam = 25 dB (different from Table 3.2-14)
  TDMA/Scanned Beam = 40 dB

Table 3.2-19. Earth Station and Satellite Average EIRP Requirement (Station Diversity)

System	Rain Zone	Earth Station Availability %			Satellite Availability %		
		99.5	99.9	99.95	99.5	99.9	99.95
FDMA	C(B,F)	58.8	58.8	58.8	46.8	46.8	46.8
	D	64.6	64.6	64.6	51.0	51.0	51.0
	E	81.8	81.8	81.8	62.1	62.1	62.1
TDMA Fixed Beam	C(B,F)	58.3	58.3	58.3	47.7	47.7	47.7
	D	60.7	60.7	60.7	48.7	48.7	48.7
	E	77.9	77.9	77.9	56.3	56.3	56.3
TDMA Scanned Beam	C(B,F)	54.7	54.7	54.7	46.0	46.0	46.0
	D	57.7	57.7	57.7	48.5	48.5	48.5
	E	62.8	62.8	62.8	53.6	53.6	53.6

Conditions:
- Two ES Diversity
- 1 M ES Antenna
- 1° Cell Diameter
- 1.54 MBPS Peak and average data rate
- Adjacent and co-channel isolation:
  FDMA, TDMA/Fixed Beam = 25 dB (different from Table 3.2-16)
  TDMA/Scanned Beam = 40 dB

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transmission from each earth station and the transponder. In Tables 3.2-15 and 3.2-17, peak EIRP's for the earth stations are shown, each again transmitting a single 1.54 Mbps carrier but for the TDMA cases a 27.5 Mbps burst rate is assumed. The satellite transponder EIRP's are scaled to the values required to support a data rate of 27.5 Mbps and, in addition for the FDMA case, 6 dB are added to the transponder requirement to reflect the transponder output back off required to control intermodulation products. The EIRP's therefore, are the transmitter saturated values. It is assumed that the TDMA satellite transmitters operate at saturation.

One of the difficulties attaining the desired availability in FDMA is to compensate the interference caused by the adjacent channels and co-channels. This poses a severe problem specifically for high availability in rain zones D and E. Tables 3.2-10 and 3.2-18 illustrates this point. In Table 3.2-18, the isolation of the adjacent channel and co-channel are assumed to be 25 (dB), with which even 99.5% availability is not attained for E zone, FDMA. ES requirements can be decreased 9 dB using 0.35^{0} cell sizes. ES transmit antenna gains of about 60 dBi can be achieved with 5m antennas. The 69 dB gained by these steps does not yield reasonable transmitter powers for operation in rain zones D and E at high availability even for the modest 1.54 Mbps rate assumed. The same conclusion is reached with respect to satellite transmitter power requirements. Thus the need for spatial diversity operation is apparent for achieving moderate to high availability in rain zones D and E as it is shown in Tables 3.2-16, 3.2-17 and 3.2-19.

3.2.7 IMPACT OF REDUNDANCY

Because of the relatively large contribution to outage time provided by the rain fading at 30/20 GHz, every attempt must be made to minimize the system outage attributable to component failure. The network operations and maintenance procedures must be geared to minimizing component failure, preventing such failures from disrupting the remainder of the network, when they do occur, and insuring that necessary repairs may be made in a timely manner. This redundancy analysis provides an opportunity not only to specify the degree of redundancy required in the earth station design, but also to specify MTTR goals which must be met by the operation and maintenance procedure of the network. This analysis is based upon several assumptions. These include:

1. System down time due to component failure should be an order of magnitude less significant than the outage due to rain fading (e.g., if total link availability is 99.5%, then earth station availability in terms of equipment should be at least 99.95%).

2. Owing to the modular nature of the hardware, the Mean Time To Repair (MTTR) a CPS earth station will be dominated by the service technician's travel time. As a result, the in MTTR goal has been set at 3 hours.

3. Baseband technologies at 30/20 GHz are fundamentally the same as those employed today at lower frequencies, and hence may be classified as mature.

4. In the time frame of CPS implementation, the RF subsystem technologies also will have matured. In this respect the individual MTBF of the various elements will correspond to todays C-band experience, i.e,:

- Antenna, waveguide	1,000,000 HRS.
- Frequency converter	25,000 HRS.
- HPA	25,000 HRS.
- LNA	25,000 HRS.
- Modem	75,000 HRS.
- Controller	80,645 HRS.
- Network Memory Sequencer(TDMA)	80,645 HRS.
- Tl Port Card	50,000 HRS.

System availability in terms of component effectiveness depends on the MTTR and the MTBF of the system as a whole. It is defined as the ratio of total operating time to total operating time plus repair time:

$$A = \frac{MTBF}{MTTR+MTBF}$$

The link availabilities under consideration range from .99 to .9995. This produces a range of earth station availabilities from .999 to .99995. As it is expected that the .9995 link availability figure will be required to attract the telephony customers which have been projected as a major portion of the eventual CPS customers, the redundancy analysis shall be driven by the more stringent equipment availability goal of .99995. Some additional

formulae are required to perform the redundancy analysis. One is for the MTBF of a string of simple components, each with a specified MTBF. Its form is similar to the expression for the total resistance of a parallel network:

$$MTBF_T = [\Sigma \frac{1}{MTBF_i}]^{-1}$$

Additionally the MTTR of the string of components is dependent upon the individual elements in the string:

$$MTTR_T = MTBF_T \Sigma \frac{MTTR_i}{MTBF_i}$$

In this analysis it has been assumed that the MTTR of all components is dominated by technician travel time. Each component then has a MTTR of three hours and the total is also three hours. Another equation necessary to the analysis is the MTBF of a redundant group of components. It can be expressed in terms of the non-redundant MTBF and the MTTR:

$$MTBF_{T(RED)} = \frac{MTTR_i}{(MTBF_i)^2}$$

where i represents the number of elements in the configuration.

Returning to the definition of availability will produce the $MTBF_T$ goal for a CPS station. Assumptions made above yield an MTTR of three hours and an availability requirement of .99995,or:

$$.99995 = \frac{MTBF}{3 + MTBF};$$

$$MTBF = 60,000 \text{ hours}$$

The figures of component availabilities combined with the $MTBF_T$ equation yield a non-redundant equipment availability of 5,600 hours. This figure clearly shows that some degree of redundancy will be required to make the effects of component failure effectively minimal in terms of total link availability. First order approximation of redundancy requirements suggests that all common components with a MTBF of less than the 60,000 hour goal must be made redundant. Such a configuration experiences a total MTBF of 17,000 hours. Note that even though the components with the lowest MTBF have been made redundant the 60,000 hour goal has not been met. The now redundant

components also comprise a large fraction of the total earth station cost, but the availability goal cannot be achieved without the redundancy of these components. Some cost savings may be realized through the use of the redundant HPA in the fade control strategy. When neither HPA has failed the stand-by module could be switched on during a rain fade and the output power summed with the on-line HPA for a 3 dB increase in the uplink transmitter output power.

The remaining component with a MTBF of less than 60,000 hours is the interface port card. As the number of these varies with the throughput of the CPS station, a 1:N redundancy configuration is recommended to provide a commonality of design amongst station with varied aggregate bit rate, as well as minimizing the cost of redundancy. The formula for the MTBF of identical elements in a 1:N redundant configuration is based upon the binomial distribution. It represents the probability that no more than two of the units have failed. The availability of the redundant configuration is then:

$$A_T = A^{N+1} + (N+1)(1-A)A^N$$

Availability can be related to the MTBF by the following equation:

$$\text{MTBF} = \frac{(\text{MTTR})\ (A)}{(1 - A)}$$

The availability of an individual port card is .99994. A conservative design goal is to size the 1:N configuration to have an MTBF equivalent to that of the antenna subsystem (1,000,000 hours) or an availability of .999997. With N=30 the MTBF of the port card configuration is equal to over 1,000,000 hours. With the modems also made 1:N, N not greater than 30, the total FDMA system MTBF exceeds 60,000 hours. When the TDMA modem is made 1:1 redundant the total TDMA system MTBF is 37,000 hours. The TDMA system requires two baseband processing elements, one for burst and synchronization control and one for DAMA and network functions. Making one of them redundant will provide a system MTBF of over 60,000 hours.

In summary, in order to provide an earth station availability which is at least one order of magnitude better than the link availability design criteria, all common equipment, save the site control processor and the

antenna, needs to be 1:1 redundant. Any per channel equipment (port cards, FDMA modems) needs to be 1:N, with N not more than 30.

3.2.8 FADE ADAPTATION STRATEGIES

Table 3.2-20 is a matrix representation of the top level system issues influencing the ranges of application of each fade control strategy. One significant impact due to spacecraft design is the difference between non-demodulating and demodulating spacecraft. The latter produces a connectivity in which the uplink and downlink are decoupled (i.e. a fade on the uplink produces no degradation in the downlink). Link performance is specified by the C/N of each individual link and the resulting BERs are summed to find the total error rate on the link. This means that the up and downlink margins cannot be shared in the same way, as in a non-demodulating spacecraft, however the opportunity exists to implement the fade control algorithm on board the spacecraft so that the unfaded portion of the link may be operated normally.

Particular payload architectures better support some fade control algorithms that others. For example, SS-FDMA is more suited to adaptive power than either adaptive FEC coding or space diversity. This is because the latter two techniques are not as compatible with the FDMA multiple access protocol. With fixed channel data rates, FEC coding produces a degradation in service due to a reduction in transmitted information bits. While this technique maintains link availability, it reduces the per circuit availability. This technique may at times cause active circuits to be dropped from the network. This is regarded as unacceptable to most telecommunications users.

The detriments of space diversity as applied to SS-FDMA systems, although not quite as severe, still present obstacles to is implementation as a fade control strategy for FDMA. This technique should employ a hitless switchover in order to facilitate high quality, highly available services. Because the switchover requires interaction from two non-collocated sites, the process requires a finite amount of time to occur. This poses synchronization problems on a continuously operating link. Received data synchronization may be maintained by having both primary and diversity site demodulators operate simultaneously, with the switchover control unit feeding the appropriate channels to the baseband hardware. However, precise synchronization is required of the uplink switchover. This is to ensure that there are no abrupt

Table 3.2-20. Application of the Fade Adaption Strategies

	ADAPTIVE POWER CONTROL	ADAPTIVE FEC	SPACE DIVERSITY
SS/TDMA	• REQUIRES AGC ON NONFADED LINKS • REQUIRES OVERSIZED HPA	• REQUIRES NETWORK PLAN ADJUSTMENT • SIMPLE IMPLEMENTATION ON UPLINK FADE, SWITCH IN CODEC • CODING MUST BE USED AT ALL DESTINATION STATIONS • REVERSE OPERATION IS COMPLEX	• TWO SITES MUST BE IN THE SAME BEAM • HITLESS SWITCHOVER CAN BE ACCOMPLISHED DURING TIME STATION IS NOT TRANSMITTING
SCAN/PROC/TDMA	• DOWNLINK AND UPLINK CAN BE LOGICALLY SEPARATED • DOWNLINK FADE MAY NOT REQUIRE UPLINK POWER CONTROL	• IMPLEMENT CODING/DECODING ON THE SATELLITE. THIS ELIMINATES PROBLEMS OF CPS STATION SENDING OR RECEIVING A MIX OF CODED AND UNCODED TRAFFIC	• NO ADVERSE EFFECTS UPON SPARE SEGMENT, IF TWO SITES ARE IN SAME BEAM AREA
SS-FDMA	• CAUSES INCREASE IN THE INTERNAL NOISE DUE TO INCREASED INTERMODULATION • ROBS POWER FROM UNFADED LINKS ON DOWNLINK ADAPTION	• CODING ADAPTION NOT POSSIBLE W/O A RATE ADJUSTMENT • THIS IS IMPOSSIBLE IN TERMS OF MOST PROTOCOLS AND VOICE TRAFFIC	• COMPLEX INTERFACE/DIVERSITY LINK REQUIREMENTS DUE TO MULTIPLE CHANNEL OPERATION • HITLESS SWITCHOVER IS EXTREMELY COMPLEX
FDMA/TDMA	• UPLINK AND DOWNLINK SEPARATED BY BBP • DOWNLINK POWER CONTROL CAN BE IMPLEMENTED ON SATELLITE • NON-FADED DOWNLINK STATIONS REQUIRE AGC	• CODING POSSIBLE TO OVERCOME DOWNLINK FADES, BUT MUST BE IMPLEMENTED ON BOARD SPACECRAFT	• SIMILAR DRAWBACKS AS SS-FDMA

changes in carrier or bit timing which would disrupt the demodulation process at the other end of the link. This not only requires precise delay measurements of the diversity interconnect so that data is arriving at each modulator within the same bit period, but also maintaining precise phase alignment of each stations carrier. Additional cost and complexity are added in the case of a multichannel FDMA earth station. Multiplexers must be used on either end of the diversity link or else coaxial cable plant must be used in a FDMA mode to pass the individual channels.

For TDMA systems adaptive power control has limited application as many stations are sharing the same carrier. This excludes the possibility of downlink fade compensation by the use of increased power output. This could produce unacceptably high signal levels at the non-faded downlink stations. Uplink power control may be used to overcome uplink fades so long as the signal flux density at the spacecraft receive antenna remains within the nominal link values.

Adaptive coding techniques can be used to overcome both up and downlink fades. Use of this fade control technique requires a network plan adjustment and hence coordination amongst all stations. This is because in order to maintain all calls in process the total transmitted bits between stations connected by a faded link must increase. Application of FEC coding to a data channel requires that the information rate be reduced to accommodate the coding bits, or that the total transmitted bits be increased to accommodate coding on top of the initial information rate. The network plan alteration required is much more severe when a downlink. This is due to the fact that all stations transmitting data to the faded station must encode all data to that station resulting in many altered bursts.

Space diversity does not require any adjustment in network plan. The switchover can take place in a manner which is transparent to the network.

Forward Error Correcting codes represent the most simply implemented form of fade compensation. Implementation involves only the addition of an FEC encode/decode module to the earth station and a switchover network to allow it to be brought on line in the presence of a fade. Implementation of adaptive power control is a bit more complex to implement. This is because the output

power must be step controlled based upon the severity of the fade in order to maintain efficient transponder operation and to be sure that the power boost on the uplink does not "capture"the transponder. Space diversity is by far the most complex to implement. This is because of the interconnecting link which must be provided as well as the switchover unit and the delay compensation buffer.

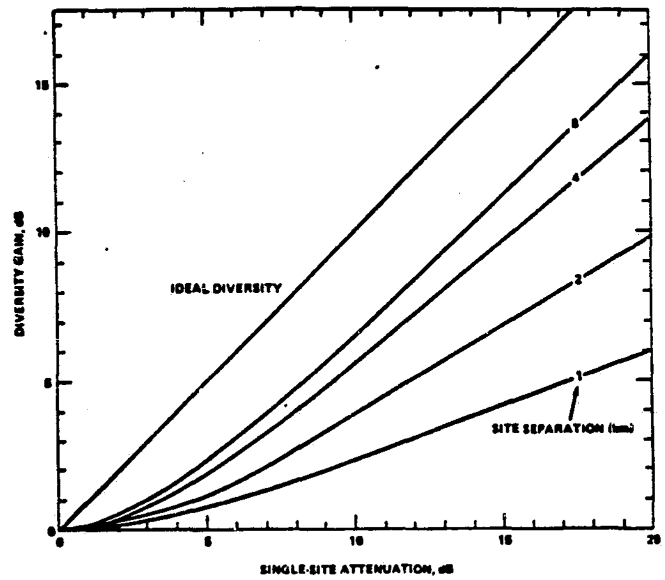
As far as the theoretical possibility for gain from each of the techniques is concerned, the ranking is a bit different. The possibility for gain from adaptive power control is virtually unlimited, the only restrictions arising from the power supply technology and of course the TWTA cost. The maximum practical gain from FEC coding is around 9 dB. The effectiveness of space diversity is a function of the site separation and the local rain statistics. Figure 3.2-20 demonstrates the gain realizable from this technique.

The conclusion that can be drawn from this data is that one particular technique may not be sufficient to provide the necessary fade margins and that a combination of approaches may be advisable. For example in the case of TDMA coding gain can provide the desired availability in several rain zones, but not for the entirety of CONUS. However, space diversity paired with adaptive coding will provide the needed margins in the areas of heavy rainfall.

3.2.9 SIGNALING/SWITCHING/SYSTEM CONTROL

To realize the full TDMA system potential, each station transmits in bursts only long enough to carry its current traffic volume. Thus, the length and position of the burst in the TDMA frame must be varied in a coordinated manner in order to avoid interference. In a spacecraft switched system,the routing of the signals through the different beams must also be coordinated with the traffic flow between the stations in the different beam coverages. For a scanning beam satellite, the beam scan must match the burst time assignment for transmission and reception at each station.

The complex coordination tasks needed to achieve efficient utilization of the frame time with SS-TDMA transmission in systems with varying traffic patterns can best be handled by a central computerized controller. The data base for computation may be provided by different means, depending on the system application and message format. For systems that do not use packet switching, transmission between stations may be channelized in standard increments such



Data Courtesy 1978 Ford Aerospace Study

Figure 3.2-20. Potential Gain Obtainable Through the Use of Space Diversity

as T1 (1.544 Mb/s). Changes in the number of channels and their routing are expected to be relatively infrequent, typically a time-of-day dependent function.

As traffic volume and channel routing may change very quickly for each station in a CPS system, however, rapid on-demand link establishment is a desirable feature. These characteristics require faster processing of the data base, which, in this case, furthermore tends to be much longer, based on the large population of CPS terminals.

In any system application, the central coordinating processor must know the traffic demands at each earth station, and must return burst assignment information to the stations. For SS-TDMA systems, this processor must also control the beam connectivity switching matrix and the beam scan pattern in the satellite. Communications links must therefore, be established between the central controller and the satellite and all earth stations. Such links are also necessary for performance moni toring and alarm functions in the system. These may include carrier power control, both on the ground and in the satellite, to overcome temporary fades.

With a regenerative satellite, all these links can be implemented via the bursts generated by the earth stations. However, this is not the most reliable method because of rain fades. Instead, the links between the central controller and the earth stations may be implemented through redundant terrestrial links, and communication with the satellite handled via a separate monitor and control channel, e.g., at C-band. This channel is narrowband, requiring only a small antenna and low power transmitter both on the ground and in the satellite. In addition, earth stations often employ voice circuits for maintenance purposes, and these so-called orderwire circuits are typically carried as part of the transmit burst overhead in the TDMA format.

Changes in the coordinated patterns of TDMA burst and beam switching and/or scanning must be accomplished without errors or interruption in the traffic. The switchover from old to new patterns must thus be performed by the stations and the satellite in such a way that the switchover appears simultaneous from the viewpoint of the satellite. A longer frame than the TDMA frame must, therefore, be introduced. (The TDMA frame is typically the same as the beam switching or scanning sequence length.) The TDMA frame, being in the order of a millisecond in length for high data rate systems, is shorter than the differential in propagation time from the satellite to various earth stations. If switching to a new pattern is to take place at a frame boundary, this differential can cause an ambiguity regarding which frame boundary to use, and a collision of bursts arriving at the satellite can occur. The TDMA frame is also about as long as the satellite propagation delay variation due to diurnal positional drift. Beam switching and/or scanning pattern changes could thus suffer from ambiguity as well.

A TDMA Superframe, containing a number of TDMA frames, can overcome this. The Superframe is usually at least 0.25 sec long, covering the round trip delay through the satellite. The Superframe boundary is marked as an inversion of the digital Reference Unique Word generated by the reference stations, or by the satellite, if a regenerative satellite is used. The earth stations indicate their Superframe boundaries by inverting their Local Unique Words in the corresponding TDMA frame. Synchronization is achieved by having each station listen to its own transmission, as echoed by the satellite, and adjusting the timing of the Superframe marker so that it occurs in the TDMA frame which has the inverted Reference Unique Word. When all stations have done this, their Superframes are synchronized. Synchronous changes of beam

switching or scanning patterns are easily achieved in a regenerative satellite, since it then can be the master for the Superframe as well as TDMA frame timing. Otherwise, ground reference stations must have special synchronization circuits to enable them to synchronize their frame positions and frame rates to the satellite frame via echoing through specific loopback beam connectivities. Further, the performance monitoring and control channel for the satellite must give a Superframe marker to the satellite, so that beam control can be synchronized to burst allocation switchover.

The Superframe permits the central controller to transmit new data for bust allocation and beam control between two Superframe boundaries, and use the boundary as an implicit simultaneous switchover command for all stations. This implicit command is naturally bit error resistant. A high degree of bit error resistance is essential in the transmission of the control data to the stations. It also helps to verify the correct reception by each station before switchover takes place. The central controller therefore, sends the information, asks for verification of correct reception and retransmits it to stations that fail to verify. If these stations still do not verify, a switchover inhibit is sent to all stations.

In a large network, a considerable amount of data must be sent to and from the central controller in a Superframe. If telephone lines are used for this purpose, Superframes are justified which are considerably longer than would be needed just to overcome the ambiguity of the TDMA frame count. The length may be bounded by the speed of reconfiguration needed to keep pace with traffic pattern changes. For trunking systems, these changes are quite gradual, but for CPS networks, reconfiguration must be rapid enough to respond to instantaneous demands.

In FDMA systems, network synchronization is maintained through the use of reference frequencies rather than the use of time reference markers. Frequency reference is required in order to ensure that proper channel spacing in the transponder is maintained. One method of distributing this frequency reference is through the incorporation of very stable oscillators in the CPS earth station design. Frequency stability can be verified through the inspection and tuning of the local oscillator at periodic inspection intervals, as well as routine checking of each downlink channel placement by the Master Control Terminal. Alternatively, the frequency reference can be

established as the carrier frequency of the downlink signaling channel to the CPS stations. With a baseband processing spacecraft, the frequency reference would have to be on the satellite. This latter approach has the advantage of reducing the cost of the CPS station at the expense of making the entire network susceptible to disruption from the loss of the centralized frequency standard.

It is advisable to have at least two levels of signaling within the CPS network. There may be sub-levels within the two major levels identified below. One major level would involve the management of connectivity between individual DTEs. This call management function is typically implemented in the terminal devices themselves or the switching units which will be external to the CPS network. Such signaling can be implemented in-band (one of the 64 kbps circuit slots in the DS-1 frame) or by a common channel signalling scheme implemented in the overhead of the DS-1 frame. Typical examples include PBX to PBX trunk management in response to hand set DAMA requests, or terminal to CPU log in procedures. All of these functions are independent of and transparent to the CPS network control and bandwidth assignment procedures.

The other level of signalling involves the assignment of T1 channels between the various CPS stations. Coordination of T1 circuit assignment within the satellite network is managed and coordinated by a central control processor. T1 channels are assigned by distributing frequency assignments to the origin and destination earth stations over the Common Signaling Channel. Some data protection is required to ensure correct reception of the assignment messages. A positive acknowledgement protocol is recommended to prevent frequency assignments in error from interfering with ongoing traffic.

3.3 NETWORK CONTROL CENTER

The Network Control Center insures reliable and effective operation of the earth/space segment network. The center provides such key operational functions as allocation of network bandwidth to links between earth stations, provision of a reference standard to insure proper channel slot occupancylmh, initialization of earth stations into the network and fade control monitoring. The network control center also performs various maintenance functions to acceptable operation of the network, including channel quality monitoring, earth station status monitoring and fault isolation and diagnosis.

Table 3.3-1 identifies the major areas of NCC operation for each of the primary multiple access techniques. The functions monitor and control the communications system only. Launch control, TT&C and other control functions are processed and executed in logically and physically distinct facilities.

Figure 3.3-1 is a block diagram of the Network Control Center. The NCC consists of three major segments: transmit and receive hardware, processing, and memory. These three segments operate upon orderwire and network traffic information to insure proper functioning of the circuits in the CPS network. Failure events at any point in the network trigger alarms, which in turn initiate maintenance/repair actions.

The NCC costs consist of facility costs which include buildings, land, power supplies and furnishings; communications hardware (RF Subsystem and modulation/demodulation equipment); computers, dedicated I/O boards, and memory and software (development and maintenance).

An estimate of the NCC costs is given in Table 3.3-2. A CPS network would typically contain only one, or at most, two NCC's. The data presented in Table 3.3-2 demonstrates that the cost of the NCC, including software development, is relatively insensitive to the choice of the system access method. The NCC cost is only a fraction of a percent of the total CPS space segment and ground segment costs.

3.4 EQUIPMENT COST COMPILATION

There are two major parameters which will have a large impact upon the CPS configuration costing. The first is the total number of units purchased in each earth station configuration. The quantity discounts which can be realized will be important when a determination needs to be made as to the optimum combination of earth stations and ground networking. Learning curves for the various earth station components are identified and their effects on CPS configuration costing are evaluated.

The other significant parameter in CPS earth station costing is the average aggregate throughput of an earth station in the network. In the TDMA configurations, as the average traffic carried by an earth station increases, the burst rate must increase in order to keep the TDMA induced delays low. In an FDMA configuration, as the aggregate traffic through an earth station

Table 3.3-1. Network Control System Functions*

- TDMA
  - BURST POSITIONING
  - FRAME SYNCHRONIZATION
  - SATELLITE SWITCH CONTROL
  - FADE CONTROL
  - NETWORK MAP GENERATION AND DISTRIBUTION
  - EARTH STATION STATUS REPORTING
  - DOWNLINE CONTROL OF EARTH STATIONS
  - INITIALIZATION OF EARTH STATIONS
- FDMA
  - FREQUENCY REFERENCE
  - FADE CONTROL
  - FREQUENCY ASSIGNMENT (MONITORING AND CONTROL OF AVAILABLE FREQUENCY POOL)
  - SATELLITE SWITCH CONTROL
  - EARTH STATION STATUS MONITORING
  - DOWNLINE CONTROL OF EARTH STATIONS

*NOTE THAT TT&C IS HANDLED BY A DISTINCT CONTROL SUBSYSTEM

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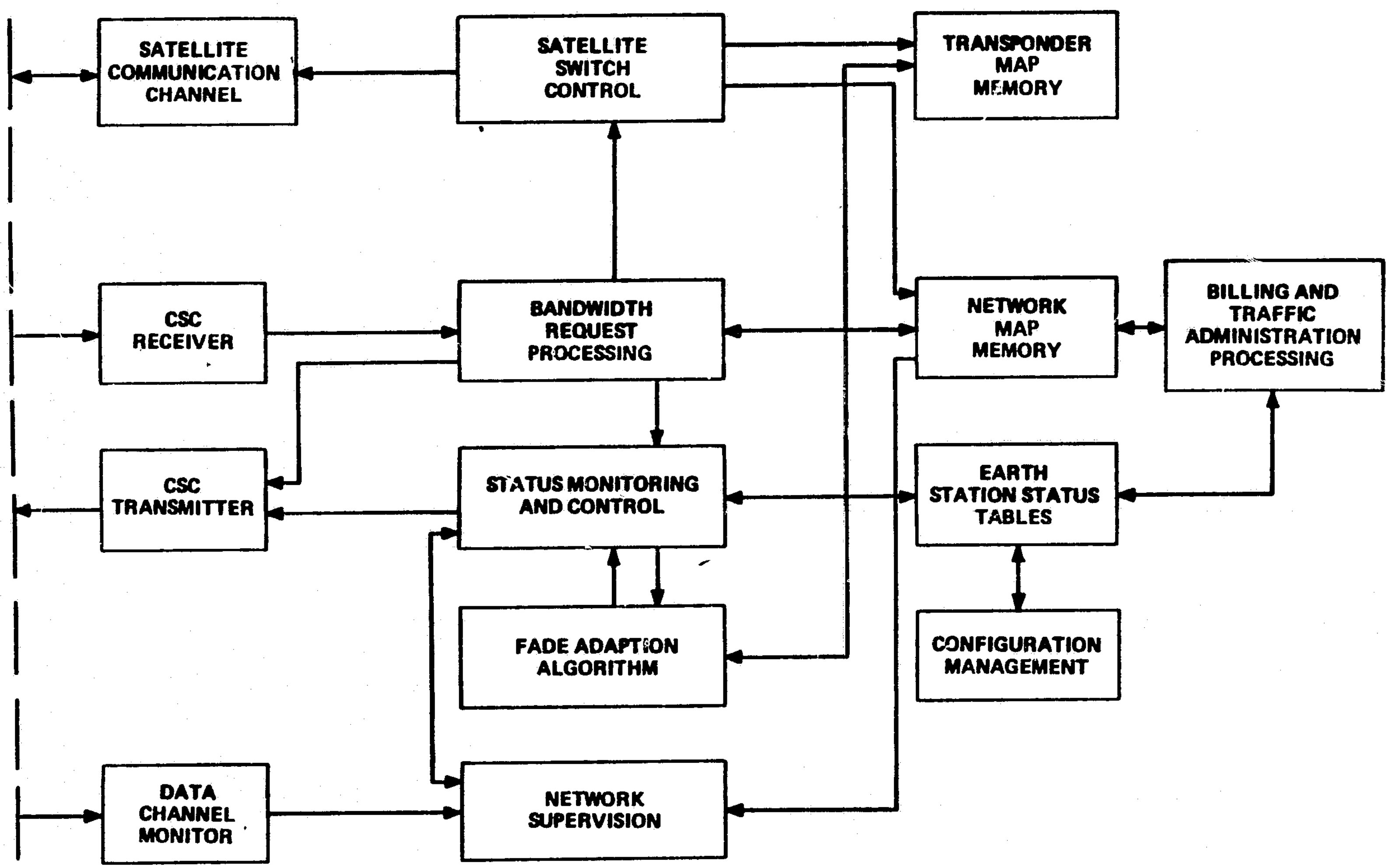

Figure 3.3-1. Top Level Network Control Center Block Diagram

Table 3.3-2. Network Control Center Cost Estimates ($000 Omitted)

SS-TDMA		SS-FDMA		SCANNING BEAM TDMA	
• FACILITY	$1,000	• FACILITY	$1,000	• FACILITY	$1,000
• RF SUBSYSTEM	$ 175	• RF SUBSYSTEM	$ 300	• RF SUBSYSTEM	$ 205
• BURST MODEM	$ 37	• FREQUENCY REFERENCE	$ 20	• BURST MODEM	$ 75
• FRAME SYNCHRONIZE		• CHANNEL MONITOR	$ 75	• FRAME SYNC	
• SUPERFRAME SYNC		• ORDERWIRE MODEMS	$ 50	• SUPERFRAME SYNC	
• DAMA REQUEST		• DAMA REQUESTS		• BURST ADJUST	
• NETWORK MAP	$ 300	• FADE CONTROL		• DAMA REQUEST	$ 400
• FADE CONTROL		• SWITCH CONTROL	$ 100	• NETWORK MAP	
• SWITCH CONTROL		• FAULT MONITORING		• FADE CONTROL	
• FAULT MONITORING		• SOFTWARE		• BEAM CONTROL	
• SOFTWARE	$ 250			• FAULT MONITOR	
				• SOFTWARE	$ 300
—TOTAL	$1,662	—TOTAL	$1,645	—TOTAL	$1,980

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increases, so does the number of channels. This, in turn, increases the filtering requirements and the rated power requirements of the local HPA. This power requirement rises faster than linearly because the intermodulation constraints grow progressively more severe as the number of FDMA carriers increases.

The equipment lists for the individual CPS configurations form a unified basis for all costing. Note that configurations are costed that include the degree of redundancy that was shown to be required in the availability analysis. All elements required for a completely installed earth station have thus been included in the costing. The categories from which these costs arise consist of electronic hardware, software modules, racks, patches and cables, shelter, environmental control, site preparation, integration, installation and test labor, and frequency clearance.

Costs for network and DAMA management are assumed to be effectively the same for all of the potential network architectures and hence will not affect the outcome of the service costing comparison. As the cost of such procedures will be shared by all stations in the CPS network, they are best described as a part of network operation and maintenance (O&M). The costs associated with O&M are considered as a fixed percentage of the installed hardware costs for the purposes of the service costing companions. This percentage is based upon industry experience.

3.4.1 DEVELOPMENTAL AND MANUFACTURING CONSIDERATIONS

This section identifies the expected level of technology development as it affects the components that will be required to construct the various CPS earth station configurations. This knowledge is required in order to project the expected cost levels and potential quantity discounts that may be available at the time of a CPS network implementation at 30/20 GHz. The cost levels depend, in part, on the maturity of the technology. This is because as the technology of a given component matures, the cost of such a component typically drops. This cost reduction can result from a number of factors, including amortizing the development costs over a larger number of units, an increase in the demand for a new component after its reliability and effectiveness have been proved in initial installations leading to increased volume of production, decreases in unit marketing costs as volume increases and reductions in cost due to increased manufacturing efficiency.

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These cost reductions can typically be quantitatively expressed by "learning curves". These curves typically exhibit exponential characteristics and may be generally described as being of the form:

$$C_{pu} = C_{su} L^{\log_2 N}$$

where:

C_{pu} = unit cost for quantity production of N units

C_{su} = single unit cost (N=1)

N = quantity produced

L = rate of the learning curve.

Note that values of L always fall between 0 and 1. A rate value which is very close to 1 is generally indicative of a highly mature technology. In such a case, the cost is relatively insensitive to production volume. Conversely, smaller rate values are associated with new or developing technologies.

The formulation of the learning curve equation presented above exhibits a factor of L decrease in production cost for each doubling in production volume. Thus the rate value is expressed as "per octave". In order to formulate and apply a learning curve, only the following assumptions must be met:

1. There must generally be more than one manufacturer, so as to avoid an economically inefficient monopoly situation.
2. Production volumes must be sufficient so as to justify investment of capital in research and development and in production efficient manufacturing equipment and techniques.
3. The manufacturing process must be sufficiently standardized so that breakthroughs occur rarely.

The rate factors (L) which apply to the various components are determined from actual industry experience. Typically L ranges from .98 to .90 depending on the type of component under consideration.

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Due to the fact that relatively few pieces of commercial K_a band hardware are currently available, price schedules specifically tailored to K_a band cannot readily be obtained. As a result the learning curves for the CPS hardware procurement have been derived from the historical maturation of C band technology. The assumptions behind this use of C band statistics include the following:

1. As the demand for K_a band equipment increases (e.g., due to traffic congestion at the lower frequency bands), the requisite development and manufacturing resources will be committed by the respective device component and subsystem manufacturers. This commitment, in turn, will result in an increased availability of K_a band equipment at competitive prices.

2. Aside from generally higher prices for analogous K_a band equipment, the underlying K_a and C band technologies are sufficiently similar to lead to similar pricing strategies.

These assumptions are generally supported by both marketing personnel and engineers representing several satellite communications equipment suppliers. The results of the learning curve survey are presented in Table 3.4-1.

Note that while some actual experience with K_a band hardware pricing may be available in military procurements, we chose not to rely upon this alternative source of data. This is primarily because the specifications for military grade components tend to be far more stringent than those of commercial grades. This especially applies to operating temperature ranges and reliability specifications. As a result, the prices for military grade communications hardware tend to exceed those for commercial grade equipment.

Table 3.4-1. Manufacturing Learning Curve Summary

Component or Subsystem	Learning Curve Rate (L)
Baseband Hardware	.93
Frequency Converter	.95
Modem	.93
HPA	.95
LNA	.95
Antenna	.95
Shelter	.98

3.4.2 CPS EARTH STATION EQUIPMENT COST COMPILATIONS

This section presents the costing data used to derive the CPS earth station costing and provides budgetary cost estimates of a redundant and non-redundant configuration for several viable spacecraft concepts. The component costing information has been obtained, in part, from previous studies performed for NASA, as well as recent manufacturing experience in the design, manufacture and installation of low-cost earth stations. After a discussion of the cost-versus-performance of the various K_a band components, earth station budgetary equipment cost estimates are compiled. These budgetary figures are based upon small quantity production runs. The following section then considers the impact of siting, clearing and installation of the CPS earth stations for a wide range of total installed stations.

Subsystem Costing

These cost estimates are based upon the study performed by Ford Aerospace and Communications Corporation in 1978 on the 30/20 GHz development program, as well as current costing for baseband hardware as it exists for C band systems. An extensive manufacturer survey was compiled, to which the inflationary factor must be added in order to bring the projections up to date. These estimates are still valid due to the fact that little development effort has been undertaken at K_a band other than military applications. One promising note is that extensive forays are being made into private microwave radio equipment at frequencies of 26 GHz and above. Development efforts here may prove valuable to the K_u band CPS program, particularly in the area of antenna and low noise receiver technology.

The antennas includes the reflector, feed assembly (including diplexer and rotary joint), pedestal, and support structure. Under severe environmental conditions a pressurized feed assembly is required to keep the feed and waveguide dry. If steptracking is required to point the antenna (diameter greater than 4 meters, stationkeeping accuracy of $\pm .03$), then motors, gears, servos, and control logic must be added.

Figure 3.4-1 shows the result of cost estimate studies presented in the study of K band antenna systems. The variance in the results can be attributed in part to variations in the particular antenna specifications and to a general lack of industry experience in large production runs of antenna subsystems.

The curves are adjusted to 1978 dollars and hence must have inflation into account before expression in 1980 dollars as per the contract. Extrapolation from K_u band to K_a was made by allowing for an increase of approximately 10% in reflector cost due to increased surface tolerance requirements and an additional $5,000 for additional difficulties in matching the feed.

The HPA survey and cost projection was performed in a similar manner. The cost data was derived from two sources: direct vendor contact and extrapolation of data available for K_u band HPAs. Direct contact of vendors proved to be of little value to Ford due to the initial stages of development, if any. Vendors contacted as a result of this study had little more to report. Extensive data is available of HPAs at K_u band and was compiled to produce the curves shown in Figure 3.4-2. An extrapolation of HPA costs from K to K_a band is somewhat subjective due to the lack of development at K_a band. The tube and cooling system are subject to cost increases, while the power supply, packaging assembly and test costs would remain relatively independent of frequency. Estimates of HPA cost versus power output made in the study may be found in Figure 3.4-3. This curve is based on a production run of 100 units and 1978 dollars. Modification of the cost equation to express it in terms of single quantity cost at 1980 dollars yields:

$$C_1 = 6.572\ P^{0.43}$$

where:

P = HPA output power in watts

C_1 = single quantity cost in thousands of dollars

Quantity discounts can then be determined from the learning curve analysis that was developed in the previous section.

A similar curve fitting procedure was undertaken by Ford Aerospace in an attempt to project the cost for low noise receivers at 18 GHz. The results of the low noise receiver survey were plotted on a graph of cost versus noise temperature for single quantity items. The curve that was derived has been adjusted for inflation so that a single quantity cost for an LNA may be expressed as:

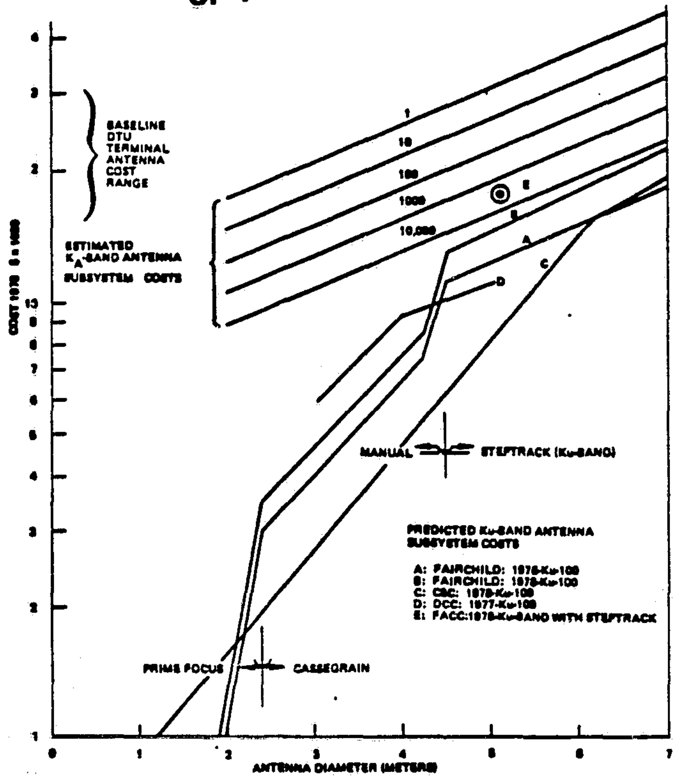

Figure 3.4-1. Antenna Cost Projections

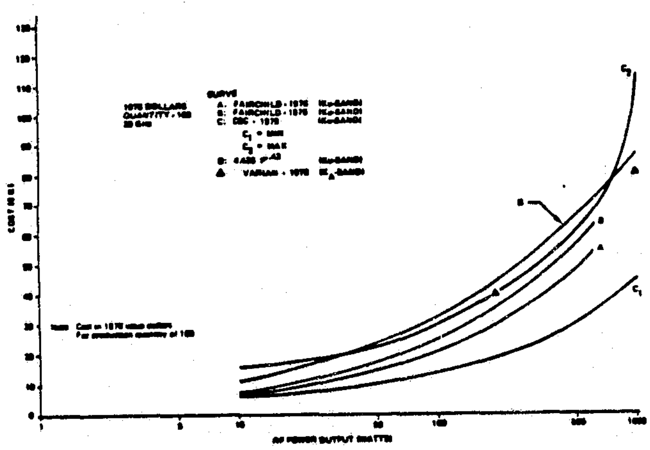

Figure 3.4-2. High Power Amplifier Survey Results

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$C_1 = 2965\ T^{-.86}$

where:

T = LNA temperature in degrees Kelvin

C_1 = unit cost of a single quantity production in thousands of dollars

The results of the curve fitting are found in Figure 3.4-4.

Configuration Costing

Representative configurations, each compatible with a particular spacecraft concept have been costed in both their redundant and non-redundant forms. The resulting equipment lists have been included in this section, with budgetary subsystem element costing for a small quantity production run. This cost

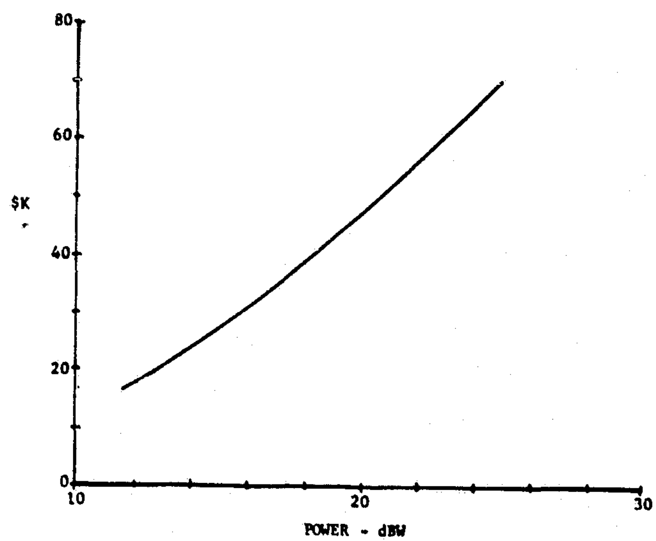

Figure 3.4-3. Estimated HPA Costs

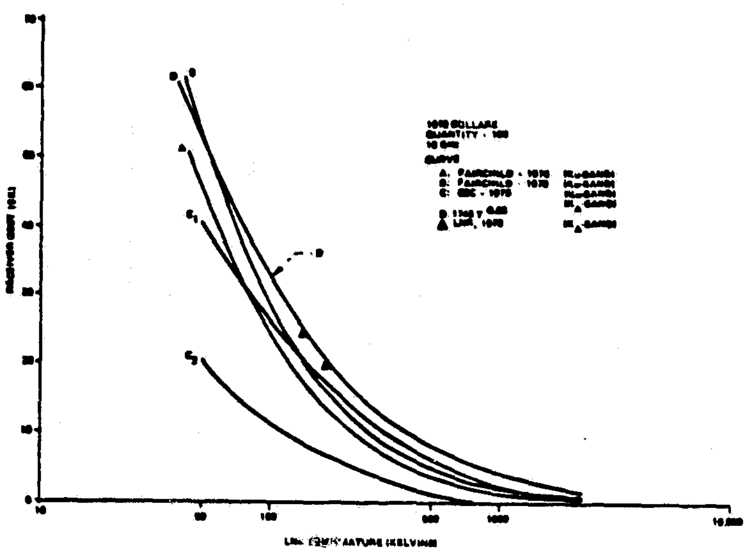

Figure 3.4-4. Low Noise Receiver Survey Results

breakdown has been provided to the subsystem level to allow future modification of the configurations as required for the end-to-end service costing analysis. The configurations which have been costed are:

1. 10 Mbps SS-TDMA earth station
2. 60 Mbps SS-TDMA earth station
3. 256 Mbps scanning beam earth station
4. SS-FDMA earth station with 4 T1 capacity
5. SS-FDMA earth station with 10 T1 capacity
6. Hybrid earth station with 10 Mbps downlink
7. Hybrid earth station with 60 Mbps downlink

These configurations were chosen, in part, to be compatible with the 10 and 40 MHz channelization scheme which has been proposed for the spacecraft. It is important to have the ground segment and the space segment compatible in terms of channelization, so as to allow the most efficient use of the available spacecraft bandwidth. The configurations also have been selected to provide a

direct comparison between the viable spacecraft concepts in terms of earth station throughput. This allows direct comparison of the alternatives in the service costing analysis.

The selection of the SS-TDMA and HYBRID earth station configurations, is also partly based upon current and projected TDMA systems. This is to allow the benefits of near-term development efforts to be shared by the 30/20 GHz program, particularly in the areas of baseband and modem implementation. Present trends indicate that 60 Mbps will become the most widely implemented burst rate in systems using one carrier per single video channel transponder It is also expected that "low-rate" SS-TDMA earth stations which partially occupy a transponder will operate at burst rates up to 10 Mbps. It is believed that this 10 Mbps threshold arises due to both throughput and economic considerations. Should the burst rate be less than the 10 Mbps configuration costed here, the configuration will be modified only in terms of the HP power rating. This will result in a cost savings of a few percent of the total installed cost of the configuration.

Redundant and non-redundant configuration budgetary subsystem cost estimates are given for each access concept at small quantity pricing, as well as total installed costs for earth station production levels of 100, 1000, and 5000. Redundant and non-redundant budgetary estimates are given so that the cost implications of increased equipment availability may be considered. Non-redundant earth stations have a typical equipment availability of .995, while the recommended redundancy configurations exhibit a typical equipment availability of .99995.

The costing analysis is presented in the tables which follow. Tables 3.4-2 through 3.4-15 show the baseline subsystem budgetary cost elements for each configuration for both redundant and non-redundant examples. The calculation of total installed cost is performed in the following section. Figures 3.4-5 through 3.4-7 are the configuration block diagrams.

3.4.2 CPS EARTH STATION INSTALLED COSTS

The equipment costs are only a part of the total installed cost. Other factors which must be budgeted include frequency coordination and clearance, FCC application, site preparation, component installation and site integration.

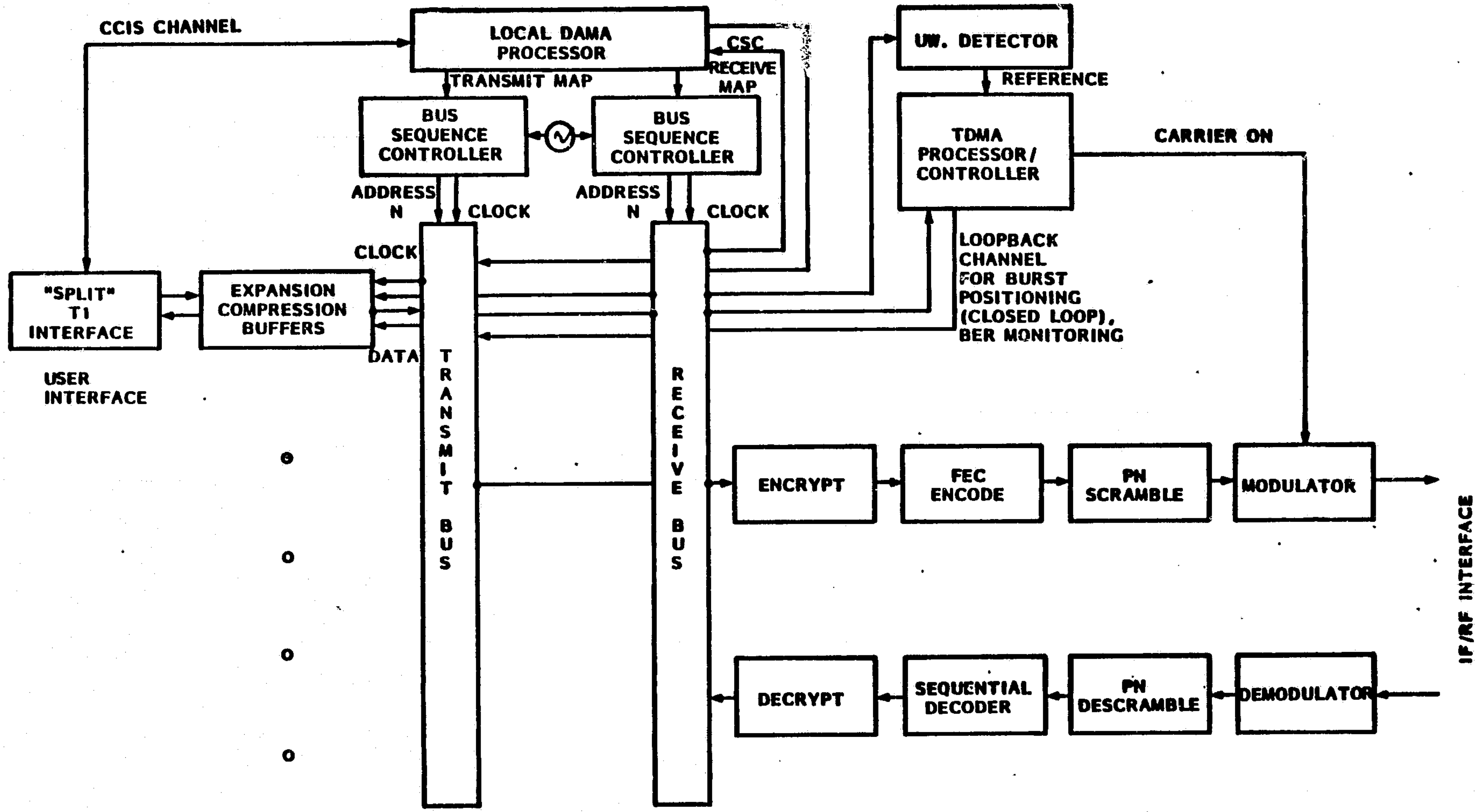

Figure 3.4-5. SS-TDMA Earth Station Configuration

WP4-01420

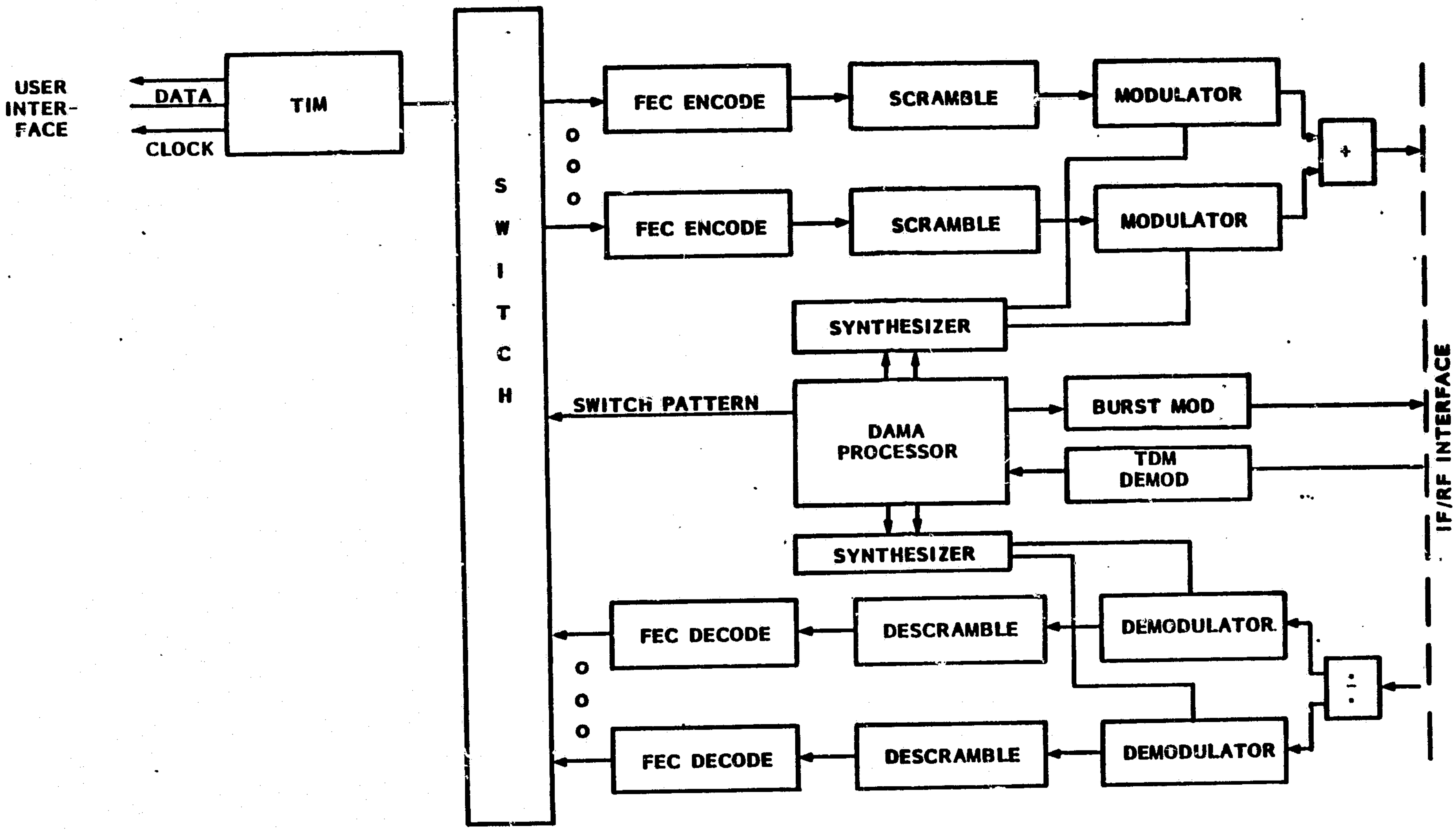

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Figure 3.4-6. SS-FDMA Earth Station Configuration

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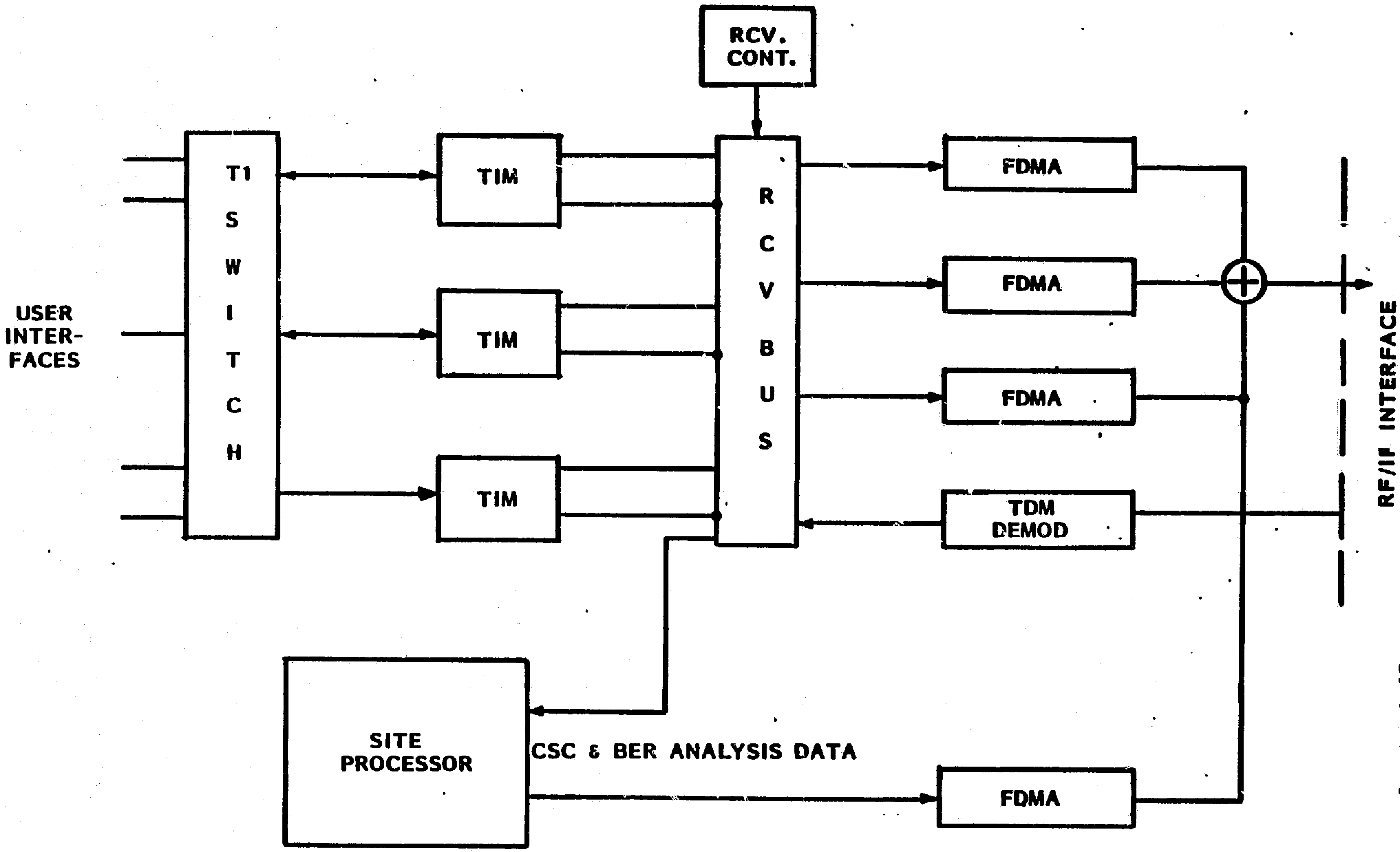

Figure 3.4-7. Hybrid FDMA/TDM Earth Station Configuration

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Table 3.4-2. Equipment Costs for a 10 Mbps SS-TDMA Earth Station

• Baseband		$ 27,000.
- 4 Split T1 Port Cards	@$ 3,000.	
- Network Memory Sequencer		
- Site Control Processor	@$15,000.	
- Performance Monitoring Unit		
- DAMA Processor		
• 10 Mbps Burst Modem		$ 25,000.
• Frequency Converter (Two Stage, Dual Conversion)		$ 30,000.
• 17 dBW Coupled Cavity TWT HPA		$ 35,000.
• 300°K GaAs FET LNA (Antenna Mounted)		$ 22,000.
• 4m Dual Polarized Antenna		$ 44,000.
- Transmit waveguide		$ 2,000.
- Transmit Reject Filter		$ 2,000.
• Racks and Patches		$ 2,000.
• Shelter (Environmentally Controlled)		$ 16,000.
• TOTAL EQUIPMENT COST		$205,500.

Table 3.4-3. Equipment Costs for a Redundant 10 Mbps SS-TDMA Earth Station

• Baseband		$ 45,000.
- 5 Split T1 Port Cards	@$ 3,000.	
- Network Memory Sequencer		
- Site Control Processor	2@$15,000.	
- Performance Monitoring Unit		
- DAMA Processor		
• 10 Mbps Burst Modem		$ 50,000.
• Frequency Converter (Two Stage, Dual Conversion)		$ 60,000.
• 17 dBW Coupled Cavity TWT HPA		$ 70,000.
• 300^{o}K GaAs FET LNA (Antenna Mounted)		$ 45,000.
• 4m Dual Polarized Antenna		$ 44,000.
- Transmit waveguide		$ 2,500.
- Transmit Reject Filter		$ 2,000.
• Racks and Patches		$ 4,000.
• Shelter (Environmentally Controlled)		$ 16,000.
• TOTAL EQUIPMENT COST		$338,500.

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Table 3.4-4. Equipment Costs for a 60 Mbps SS-TDMA Earth Station

• Baseband		$ 45,000.
- 5 Split T1 Port Cards	@$ 3,000.	
- Network Memory Sequencer		
- Site Control Processor	@$15,000.	
- Performance Monitoring Unit		
- DAMA Processor		
• 60 Mbps Burst Modem		$ 37,000.
• Frequency Converter (Two Stage, Dual Conversion)		$ 30,000.
• 25 dBW Coupled Cavity TWT HPA		$ 70,000.
• 300°K GaAs FET LNA (Antenna Mounted)		$ 22,000.
• 4m Dual Polarized Antenna		$ 44,000.
- Transmit waveguide		$ 2,500.
- Transmit Reject Filter		$ 2,000.
• Racks and Patches		$ 2,000.
• Shelter (Environmentally Controlled)		$ 16,000.
• TOTAL EQUIPMENT COST		$270,500.

Table 3.4-5. Equipment Costs for a Redundant 60 Mbps SS-TDMA Earth Station

• Baseband		$ 63,000.
- 5 Split T1 Port Cards	@$ 3,000.	
- Network Memory Sequencer		
- Site Control Processor	2@$15,000.	
- Performance Monitoring Unit		
- DAMA Processor		
• Redundancy Switchover Unit		$ 10,000.
• 60 Mbps Burst Modem		$ 74,000.
• Frequency Converter (Two Stage, Dual Conversion)		$ 60,000.
• 25 dBW Coupled Cavity TWT HPA		$140,000.
• 300^{o}K GaAs FET LNA (Antenna Mounted)		$ 45,000.
• 4m Dual Polarized Antenna		$ 44,000.
- Transmit waveguide		$ 2,500.
- Transmit Reject Filter		$ 2,000.
• Racks and Patches		$ 4,000.
• Shelter (Environmentally Controlled)		$ 16,000.
• TOTAL EQUIPMENT COST		$460,500.

Table 3.4-6. Equipment Costs for a 256 Mbps Scanning Beam SS-TDMA Earth Station

• Baseband		$145,000.
- 10 Split T1 Port Cards	@$ 3,000.	
- Network Memory Sequencer		
- Site Control Processor	@$115,000.	
- Performance Monitoring Unit		
- DAMA Processor		
• 256 Mbps Burst Modem		$ 75,000.
• Frequency Converter (Two Stage, Dual Conversion)		$ 30,000.
• 25 dBW Coupled Cavity TWT HPA		$ 70,000.
• 300°K GaAs FET LNA (Antenna Mounted)		$ 22,000.
• 5m Dual Polarized Antenna		$ 65,000.
- Transmit waveguide		$ 2,500.
- Transmit Reject Filter		$ 2,000.
- Step tracking Hardware		$ 12,000.
• Racks and Patches		$ 2,000.
• Shelter (Environmentally Controlled)		$ 16,000.
• TOTAL EQUIPMENT COST		$441,500.

Table 3.4-7. Equipment Costs for a Redundant 256 Mbps Scanning Beam SS-TDMA Earth Station

• Baseband		$163,000.
- 11 Split T1 Port Cards	@$ 3,000.	
- Network Memory Sequencer		
- Site Control Processor	@$100,000.	
- Performance Monitoring Unit		
- DAMA Processor		
• Redundancy Switchover		$ 20,000.
• 256 Mbps Burst Modem		$150,000.
• Frequency Converter (Two Stage, Dual Conversion)		$ 60,000.
• 25 dBW Coupled Cavity TWT HPA		$140,000.
• 300°K GaAs FET LNA (Antenna Mounted)		$ 45,000.
• 5m Dual Polarized Antenna		$ 65,000.
- Transmit waveguide		$ 2,500.
- Transmit Reject Filter		$ 2,000.
- Step tracking Hardware		$ 12,000.
• Racks and Patches		$ 4,000.
• Shelter (Environmentally Controlled)		$ 16,000.
• TOTAL EQUIPMENT COST		$679,500.

Table 3.4-8. Equipment Costs for a SS-FDMA Earth Station with a Throughput of 4 T1s

• Baseband		
- 4 T1 Interface Port Cards	@$ 1,000.	$ 4,000.
- Performance Monitoring Unit		$ 15,000.
- Racks and Patches		$ 3,000.
- Reference Frequency Generation (Local Oscillator or from Downlink)		$ 2,500.
• Modulation		
- Frequency Synthesizer		$ 10,000.
- 4 1.544 Mbps Modems	@$ 5,000.	$ 20,000.
- CSC Modem		$ 5,000.
• IF/RF		
- Dual Two Stage Frequency Converter		$ 30,000.
- 4 15 Watt HPAs	@$15,000.	$ 60,000.
- Power Combiner		$ 10,000.
- 300°K LNA		$ 22,000.
- Waveguide		$ 2,000.
- 3m Antenna (Dual Polarized)		$ 28,000.
- Transmit Reject Filter		$ 2,500.
• Environmentally Controlled Shelter		$ 16,000.
• TOTAL EQUIPMENT COST		$230,000.

Table 3.4-9. Equipment Costs for a Redundant SS-FDMA Earth Station with a Throughput of 4 T1s

• Baseband		
- 5 T1 Interface Port Cards	@$ 1,000.	$ 5,000.
- Redundancy Switchover		$ 8,000.
- Performance Monitoring Unit		$ 30,000.
- DAMA and CSC Processor		
- Power Supply		$ 6,000.
- Racks and Patches		
- Reference Frequency Generation (Local Oscillator or from Downlink)		$ 5,000.
• Modulation		
- Frequency Synthesizer		$ 20,000.
- 5 1.544 Mbps Modems	@$ 5,000.	$ 25,000.
- Redundancy Switchover		$ 8,000.
- CSC Modem		$ 10,000.
• IF/RF		
- Dual Two Stage Frequency Converter		$ 60,000.
- 2 15 Watt HPAs per T1 Channel	@$15,000.	$120,000.
- Power Combiner		$ 20,000.
- 300°K LNA		$ 45,000.
- Waveguide		$ 2,000.
- 3m Antenna (Dual Polarized)		$ 28,000.
- Transmit Reject Filter		$ 2,500.
• Environmentally Controlled Shelter		$ 16,000.
• TOTAL EQUIPMENT COST		$410,500.

Table 3.4-10. Equipment Costs for an SS-FDMA Earth Station with a Throughput of 10 T1s

• Baseband		
- 10 T1 Interface Port Cards	@$ 1,000.	$ 10,000.
- Performance Monitoring Unit		$ 30,000.
- DAMA and CSC Processor		
- Power Supply		$ 3,000.
- Racks and Patches		
- Reference Frequency Generation (Local Oscillator or from Downlink)		$ 2,500.
• Modulation		
- Frequency Synthesizer		$ 10,000.
- 10 1.544 Mbps Modems	@$ 5,000.	$ 50,000.
- CSC Modem		$ 5,000.
• IF/RF		
- Dual Two Stage Frequency Converter		$ 30,000.
- 10 15 Watt HPAs	@$15,000.	$150,000.
- Power Combiner		$ 25,000.
- 300°K LNA		$ 22,000.
- Waveguide		$ 2,000.
- 3m Antenna (Dual Polarized)		$ 28,000.
- Transmit Reject Filter		$ 2,500.
• Environmentally Controlled Shelter		$ 16,000.
• TOTAL EQUIPMENT COST		$371,000.

Table 3.4-11. Equipment Costs for a Redundant SS-FDMA Earth Station with a Throughput of 10 T1s

• Baseband		
- 11 T1 Interface Port Cards	@$ 1,000.	$ 11,000.
- Redundancy Switchover		$ 15,000.
- Performance Monitoring Unit		$ 30,000.
- DAMA and CSC Processor		
- Racks and Patches		$ 6,000.
- Reference Frequency Generation (Local Oscillator or from Downlink)		$ 5,000.
• Modulation		
- Frequency Synthesizer		$ 20,000.
- 11 1.544 Mbps Modems	@$ 5,000.	$ 55,000.
- Redundancy Switchover		$ 15,000.
- CSC Modem		$ 10,000.
• IF/RF		
- Dual Two Stage Frequency Converter		$ 60,000.
- 20 15 Watt HPAs	@$15,000.	$300,000.
- Power Combiner		$ 50,000.
- 300°K LNA		$ 45,000.
- Waveguide		$ 2,000.
- 3m Antenna (Dual Polarized)		$ 28,000.
- Transmit Reject Filter		$ 2,500.
• Environmentally Controlled Shelter		$ 16,000.
• TOTAL EQUIPMENT COST		$670,000.

Table 3.4-12. Equipment Costs for a HYBRID Earth Station with a Throughput of 4 T1s

• 4 T1 Port Cards	@$ 1,500.	$ 6,000.
- Elastic Buffer on Transmit Side		
- Expansion Buffer on Receive Side		
- Synchronous Interface to the Ground Network		
• TDM Receive Bus and Demultiplexing Controller		$ 10,000.
• Site Control Processor		$ 7,000.
- Performance Monitoring		
- DAMA Request Processing		
• 4 1.544 MBPS Serial MSK Modulators	@$ 5,000.	$ 20,000.
• 10 Mbps SMSK Demodulator		$ 10,000.
• IF/RF		
- Frequency Converter		$ 30,000.
- 4 15 watt HPAs (1 per T1)	@$15,000.	$ 60,000.
- Power Combiner		$ 5,000.
- 300°K LNA		$ 22,000.
- 4m Dual Polarized Antenna		$ 44,000.
- Transmit Waveguide		$ 2,000.
- Transmit Reject Filter		$ 2,500.
• Racks and Patches		$ 2,000.
• Environmentally Controlled Shelter		$ 16,000.
• TOTAL COST		$236,500.

Table 3.4-13. Equipment Costs for a Redundant HYBRID Earth Station with a Throughput of 4 T1s

• 5 T1 Port Cards	@$ 1,500.	$ 7,500.
- Elastic Buffer on Transmit Side		
- Expansion Buffer on Receive Side		
- Synchronous Interface to the Ground Network		
• TDM Receive Bus and Demultiplexing Controller		$ 20,000.
• Site Control Processor		$ 14,000.
- Performance Monitoring		
- DAMA Request Processing		
• 5 1.544 MBPS Serial MSK Modulators	@$ 5,000.	$ 25,000.
• 10 Mbps SMSK Demodulator		$ 20,000.
• Redundancy Switchover Unit		$ 10,000.
• IF/RF		
- Frequency Converter		$ 60,000.
- 8 15 watt HPAs (1 per T1)	@$15,000.	$120,000.
- Power Combiner		$ 10,000.
- 300°K LNA		$ 45,000.
- 4m Dual Polarized Antenna		$ 44,000.
- Transmit Waveguide		$ 2,000.
- Transmit Reject Filter		$ 2,500.
• Racks and Patches		$ 4,000.
• Environmentally Controlled Shelter		$ 16,000.
• TOTAL COST		$396,000.

Table 3.4-14. Equipment Costs for a HYBRID Earth Station with a Throughput of 10 T1s

• 10 T1 Port Cards	@$ 1,500.	$ 15,000.
- Elastic Buffer on Transmit Side		
- Expansion Buffer on Receive Side		
- Synchronous Interface to the Ground Network		
• TDM Receive Bus and Demultiplexing Controller		$ 10,000.
• Site Control Processor		$ 7,000.
- Performance Monitoring		
- DAMA Request Processing		
• 10 1.544 MBPS Serial MSK Modulators	@$ 5,000.	$ 50,000.
• 60 Mbps SMSK Demodulator		$ 22,000.
• IF/RF		
- Frequency Converter		$ 30,000.
- 10 15 watt HPAs (1 per T1)	@$15,000.	$150,000.
- Power Combiner		$ 10,000.
- 300°K LNA		$ 22,000.
- 4m Dual Polarized Antenna		$ 44,000.
- Transmit Waveguide		$ 2,000.
- Transmit Reject Filter		$ 2,500.
• Racks and Patches		$ 2,000.
• Environmentally Controlled Shelter		$ 16,000.
• TOTAL COST		$382,500.

Table 3.4-15. Equipment Costs for a Redundant HYBRID Earth Station with a Throughput of 10 T1s

• 11 T1 Port Cards - Elastic Buffer on Transmit Side - Expansion Buffer on Receive Side - Synchronous Interface to the Ground Network	@$ 1,500.	$ 16,500.
• TDM Receive Bus and Demultiplexing Controller		$ 20,000.
• Site Control Processor - Performance Monitoring - DAMA Request Processing		$ 14,000.
• 11 1.544 MBPS Serial MSK Modulators	@$ 5,000.	$ 55,000.
• 60 Mbps SMSK Demodulator		$ 44,000.
• IF/RF		
- Frequency Converter		$ 60,000.
- 20 15 watt HPAs (1 per T1)	@$15,000.	$300,000.
- Power Combiner		$ 50,000.
- 300°K LNA		$ 45,000.
- 4m Dual Polarized Antenna		$ 44,000.
- Transmit Waveguide		$ 2,000.
- Transmit Reject Filter		$ 2,500.
• Racks and Patches		$ 4,000.
• Environmentally Controlled Shelter		$ 16,000.
• TOTAL COST		$673,000.

The total installed cost of a CPS earth station also depends upon the total production volume of the particular configuration. This section combines all installation and quantity discount factors in order to project the installed cost of several representative configurations at production volumes of 100, 1000 and 5000.

Site Selection and Preparation

Before any CPS earth station components can be shipped, a proper site must be selected and prepared to receive the earth station. Site selection depends upon several factors, including level of interfering RF energy (microwave radio or other earth stations), adequacy of the site terrain to support the earth station, potential for access to the concentration network, availability of a lease agreement at a reasonable rate (where required) and availability of commercial power.

Any reputable nationwide frequency coordination firm can be of invaluable assistance in the site selection process.

Once a suitable site has been selected, it must be prepared so that the installation of the earth station components can proceed unhindered. Site preparation includes all civil construction required to make the site usable (clearing, grading, etc.) as well as the construction of any required access roads and other improvements required to comply with local zoning ordinances and the provision of prime power to the shelter location. To make the site usable as an earth station location, the local utility must supply a commercial power connection. All of the above considerations exhibit a cost sensitivity which is not related to the particular earth station configuration as much as the particular site involved. Therefore, the costs used in the budgetary estimates are representative of some average costs which have been experienced in recent earth station sittings.

Once the site is fully prepared, the component subsystems can be delivered to the site. At this time the integration technicians may be dispatched from the prime contractor to begin the installation and checkout of the earth station. All of the cost items in this phase of earth station installation are more directly related to the total hardware cost of the earth station. These cost items include all component shipping costs, salary and expenses for a two man installation and integration team from the prime contractor and subcontracted antenna and shelter installation (including foundation piers).

These cost items typically run from 15% to 20% of the total equipment cost of the earth station. A budgetary amount of 17% of the total hardware cost is a realizable goal.

Total Installed Earth Station Costs

Total installed cost is a function of both the degree of redundancy and the total production volume. Tables 3.4-16 through 3.4-23 are a compilation of total installed costs for several redundancy/production scenarios, which consist of:

1. Small quantity of each earth station configuration.
2. 100 units of each earth station configuration.
3. 1000 units of each earth station configuration.
4. 5000 units of each earth station configuration.

The tables show the total installed cost for redundant and non-redundant cases of each production volume identified. Table 3.4-24 is a summary of the non-recurring costs associated with each configuration, independent of the development of any other configuration. It should be noted that if more than one configuration was developed simultaneously, some of the costs could be shared.

3.5 ANNUAL EARTH STATION COSTS

Cost models have been developed for earth stations for the four system concepts (SS-FDMA, SS-TDMA/Fixed Beams, SS-TDMA/Scanning Beam, HYBRID) in terms of ES capacity requirements, burst rate, quantity produced, CONUS rain zone, availability, and the system design parameters of number of satellite

beams and ES antenna diameter. For cases of non-diversity, redundancy of earth station components have been factored into the cost model. Based on the above model, equations for installed costs are presented. In addition, non-recurring costs are presented for each concept and a means for computing initial earth station investment is given.

3.5.1 EARTH STATION EIRP REQUIREMENTS

The earth station uplink EIRP depends on all factors which enter into the link between earth station and satellite receiver as discussed in Section 3.2.6.

Since the power amplifier and antenna are major elements of the earth station cost and the requirements placed on these components are determined by the EIRP requirements, the EIRP is an important ES specification. The EIRP requirements vary with the rain zone in which the ES placed. The CONUS rain zones are shown in Figure 3.2-16. The CONUS area coverage of these zones and their traffic requirements are:

	By Area	BY CPS Traffic
Rain Zone D	49%	68%
Rain Zone B,C,F	42%	20%
Rain Zone E	9%	12%

Rain zone E has very large rainfall rates and in it the EIRP requirements become excessive and result in relatively large costs. However, it contributes only 12% of the system traffic. Consequently, special means of compensating for the effects of rain outage, such as station diversity, can be considered there without seriously increasing system costs. These considerations are characterized in the ground network cost analysis.

The earth station EIRP requirements when station diversity is employed correspond to those of stations with relatively low availabilities due to rain outage. For example, if one earth station were designed for an overall availability of 99% based on rain outages, the use of a second station sufficiently separated from the first in a two station diversity network would result in an overall availability of 99.99%.

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Table 3.4-16. Total Installed Costs for Non-Redundant ES (Small Quantity)

Earth Station Configuration

	FIXED BEAM		SCANNING BEAM				
	SS-TDMA 10 Mbps	SS-TDMA 60 Mbps	SS-TDMA 256 Mbps	SS-FDMA 4 T1s	SS-FDMA 10 T1s	HYBRID 10 Mbps	HYBRID 60 Mbps
°Survey and Coordination	$ 1,500.	$ 1,500.	$ 1,500,	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.
°Improvement	$ 10,000.	$ 10,000.	$ 10,000.	$ 10,000.	$ 10,000.	$ 10,000.	$ 10,000.
°Licensing	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.
°Hardware Costs	$205,500.	$270,500.	$441,500.	$230,000.	$396,000.	$236,500.	$382,500.
°Installation	$ 34,935.	$ 45,985.	$ 75,055.	$ 39,100.	$ 67,320.	$ 40,205.	$ 65,025.
°Total Installed Cost	$253,435.	$332,485.	$529,555.	$282,100.	$476,320.	$289,705.	$460,525.

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Table 3.4-17. Total Installed Costs for Redundant ES (Small Quantity)

Earth Station Configuration

	FIXED BEAM		SCANNING BEAM				
	SS-TDMA 10 Mbps	SS-TDMA 60 Mbps	SS-TDMA 256 Mbps	SS-FDMA 4 T1s	SS-FDMA 10 T1s	HYBRID 10 Mbps	HYBRID 60 Mbps
°Survey and Coordination	$ 1,500.	$ 1,500.	$ 1,500,	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.
°Improvement	$ 10,000.	$ 10,000.	$ 10,000.	$ 10,000.	$ 10,000.	$ 10,000.	$ 10,000.
°Licensing	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.
°Hardware Costs	$338,500.	$460,500.	$679,500.	$412,500.	$670,000.	$396,000.	$672,000.
°Installation	$ 57,545.	$ 78,285.	$115,515.	$ 70,125.	$113,900.	$ 67,320.	$114,240.
°Total Installed Cost	$409,045.	$551,785.	$920,335.	$495,625.	$796,900.	$476,320.	$779,240.

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Table 3.4-18. Total Installed Costs for Non-Redundant ES (Quantity 100)

Earth Station Configuration

	FIXED BEAM		SCANNING BEAM				
	SS-TDMA 10 Mbps	SS-TDMA 60 Mbps	SS-TDMA 256 Mbps	SS-FDMA 4 T1s	SS-FDMA 10 T1s	HYBRID 10 Mbps	HYBRID 60 Mbps
°Survey and Coordination	$ 1,500.	$ 1,500.	$ 1,500,	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.
°Improvement	$ 10,000.	$ 10,000.	$ 10,000.	$ 10,000.	$ 10,000.	$ 10,000.	$ 10,000.
°Licensing	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.
°Hardware Costs	$154,179.	$206,515.	$331,105.	$175,425.	$301,955.	$180,070.	$275,755.
°Installation	$ 26,210.	$ 35,108.	$ 56,288.	$ 29,822.	$ 51,332.	$ 30,612.	$ 46,878.
°Total Installed Cost	$193,389.	$254,623.	$400,393.	$218,247.	$366,287.	$223,682.	$335,633.

Table 3.4-19. Total Installed Costs for Redundant ES (Quantity 100)

Earth Station Configuration

	FIXED BEAM		SCANNING BEAM				
	SS-TDMA 10 Mbps	SS-TDMA 60 Mbps	SS-TDMA 256 Mbps	SS-FDMA 4 T1s	SS-FDMA 10 T1s	HYBRID 10 Mbps	HYBRID 60 Mbps
°Survey and Coordination	$ 1,500.	$ 1,500.	$ 1,500,	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.
°Improvement	$ 10,000.	$ 10,000.	$ 10,000.	$ 10,000.	$ 10,000.	$ 10,000.	$ 10,000.
°Licensing	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.
°Hardware Costs	$254,000.	$341,780.	$483,345.	$302,715.	$485,915.	$295,435.	$429,560.
°Installation	$ 43,190.	$ 58,103.	$ 82,169.	$ 51,462.	$ 82,606.	$ 50,224.	$ 73,025.
°Total Installed Cost	$310,190.	$412,883.	$578,514.	$367,177.	$581,521.	$358,659.	$515,585.

Table 3.4-20. Total Installed Costs for Non-Redundant ES (Quantity 1000)

Earth Station Configuration

	FIXED BEAM		SCANNING BEAM				
	SS-TDMA 10 Mbps	SS-TDMA 60 Mbps	SS-TDMA 256 Mbps	SS-FDMA 4 T1s	SS-FDMA 10 T1s	HYBRID 10 Mbps	HYBRID 60 Mbps
°Survey and Coordination	$ 1,500.	$ 1,500.	$ 1,500,	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.
°Improvement	$ 10,000.	$ 10,000.	$ 10,000.	$ 10,000.	$ 10,000.	$ 10,000.	$ 10,000.
°Licensing	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.
°Hardware Costs	$134,110.	$181,510.	$265,210.	$155,920.	$245,520.	$159,010.	$242,560.
°Installation	$ 22,799.	$ 30,857.	$ 45,086.	$ 26,506.	$ 41,738.	$ 27,032.	$ 41,235.
°Total Installed Cost	$169,909.	$225,367.	$323,296.	$195,426.	$300,258.	$199,042.	$296,795.

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Table 3.4-21. Total Installed Costs for Redundant ES (Quantity 1000)

Earth Station Configuration

	FIXED BEAM		SCANNING BEAM				
	SS-TDMA 10 Mbps	SS-TDMA 60 Mbps	SS-TDMA 256 Mbps	SS-FDMA 4 T1s	SS-FDMA 10 T1s	HYBRID 10 Mbps	HYBRID 60 Mbps
°Survey and Coordination	$ 1,500.	$ 1,500.	$ 1,500,	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.
°Improvement	$ 10,000.	$ 10,000.	$ 10,000.	$ 10,000.	$ 10,000.	$ 10,000.	$ 10,000.
°Licensing	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.
°Hardware Costs	$216,150.	$296,400.	$423,580.	$269,680.	$425,920.	$264,020.	$419,455.
°Installation	$ 36,746.	$ 50,388.	$ 72,009.	$ 45,846.	$ 72,406.	$ 44,883.	$ 71,307.
°Total Installed Cost	$265,896.	$359,788.	$508,589.	$328,526.	$511,326.	$321,903.	$503,762.

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Table 3.4-22. Total Installed Costs for Non-Redundant ES (Quantity 5000)

Earth Station Configuration

	FIXED BEAM		SCANNING BEAM				
	SS-TDMA 10 Mbps	SS-TDMA 60 Mbps	SS-TDMA 256 Mbps	SS-FDMA 4 T1s	SS-FDMA 10 T1s	HYBRID 10 Mbps	HYBRID 60 Mbps
°Survey and Coordination	$ 1,500.	$ 1,500.	$ 1,500,	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.
°Improvement	$ 10,000.	$ 10,000.	$ 10,000.	$ 10,000.	$ 10,000.	$ 10,000.	$ 10,000.
°Licensing	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.
°Hardware Costs	$130,675.	$167,825.	$263,775.	$144,070.	$238,635.	$140,415.	$224,705.
°Installation	$ 22,215.	$ 28,530.	$ 44,842.	$ 24,492.	$ 40,568.	$ 23,871.	$ 38,200.
°Total Installed Cost	$165,890.	$209,355.	$321,617.	$181,562.	$292,203.	$177,286.	$275,905.

Table 3.4-23. Total Installed Costs for Redundant ES (Quantity 5000)

Earth Station Configuration

	FIXED BEAM		SCANNING BEAM				
	SS-TDMA 10 Mbps	SS-TDMA 60 Mbps	SS-TDMA 256 Mbps	SS-FDMA 4 T1s	SS-FDMA 10 T1s	HYBRID 10 Mbps	HYBRID 60 Mbps
°Survey and Coordination	$ 1,500.	$ 1,500.	$ 1,500,	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.
°Improvement	$ 10,000.	$ 10,000.	$ 10,000.	$ 10,000.	$ 10,000.	$ 10,000.	$ 10,000.
°Licensing	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.	$ 1,500.
°Hardware Costs	$197,175.	$265,865.	$391,805.	$247,395.	$380,645.	$241,565.	$382,880.
°Installation	$ 33,520.	$ 45,197.	$ 66,607.	$ 42,507.	$ 64,710.	$ 41,066.	$ 65,090.
°Total Installed Cost	$243,695.	$324,092.	$471,412.	$302,902.	$458,355.	$295,631.	$460,970.

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Table 3.4-24. Total Non-Recurring Costs for Earth Stations

Earth Station Configuration

	FIXED BEAM		SCANNING BEAM				
	SS-TDMA 10 Mbps	SS-TDMA 60 Mbps	SS-TDMA 256 Mbps	SS-FDMA 4 T1s	SS-FDMA 10 T1s	HYBRID 10 Mbps	HYBRID 60 Mbps
°Software Development	$275,000.	$275,000.	$350,000,	$275,000.	$275,000.	$275,000.	$275,000.
°Systems Engineering	$150,000.	$150,000.	$220,000.	$100,000.	$100,000.	$175,000.	$175,000.
°Documentation	$ 20,500.	$ 27,000.	$ 44,100.	$ 23,000.	$ 39,600.	$ 23,600.	$ 38,200.
°Total Non-Recurring Cost	$445,500.	$452,000.	$614,100.	$398,000.	$314,600.	$473,600.	$488,200.

The earth station cost is dependent on both antenna size and HPA power. The HPA power normalized to a single T1 data rate can be computed from the EIRP values given in Tables 3.2-18 or 3.2-19 minus the antenna gain. The antenna gain at 28.75 GHz is:

$$G = 46.6 + 20 \log_{10} D - 0.07D^2 \text{ dB}$$ where D = antenna diameter (meters).

Spacecraft station keeping is assumed to be $\pm$ 0.05 degrees in this equation.

The normalized HPA power required (P_{HPA}) equals:

$$P_{HPA} = EIRP + 20 \log_{10} \alpha - 46.6 - 20 \log_{10} D + 0.07 D^2 \text{ dB}$$

where the EIRP values are from the tables in Section 3.2.6 and α is the cell width in degrees as determined by the satellite antenna beam width, see Figure 3.5-1.

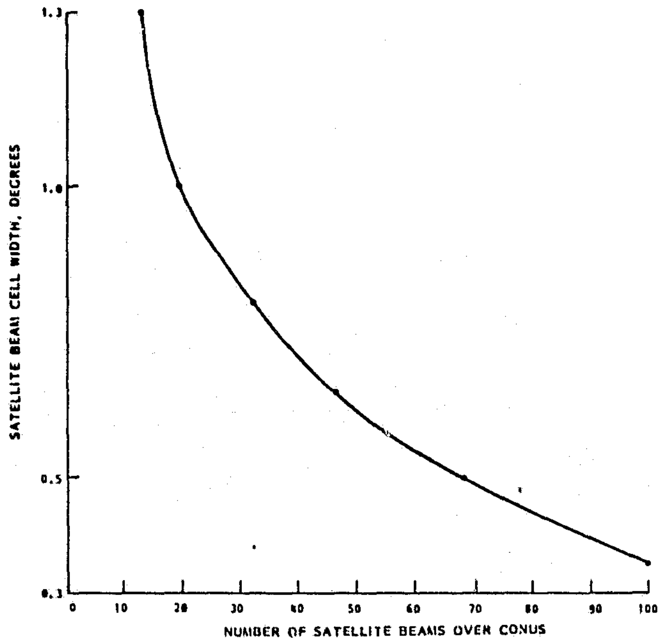

Figure 3.5-1. Satellite Beam Cell Width vs Number of Beams Over CONUS

3.5.2 EARTH STATION COST ELEMENTS

The earth station costs consist of both non-recurring costs, which includes software development, systems engineering and documentation, and the earth station installed costs, which include hardware, installation and miscellaneous costs regarding the individual site (surveys, frequency coordination, site improvement, and licensing).

The non-recurring costs show only small variation with capacity (Table 3.4-24) and for earth station costing are taken to be:

SS-FDMA	$406,000
SS-TDMA/Fixed Beam	$449,000
SS-TDMA/Scanning Beam	$614,000
HYBRID	$481,000

The total earth station initial investment equals the installed earth station costs plus the share of the non-recurring costs chargeable to the given station. The share is based on the capacity of the earth station in question to the total capacity of all earth stations of that design. With a nominal number of earth stations of a given type utilized, the non-recurring costs are a relatively small part of the earth station costs.

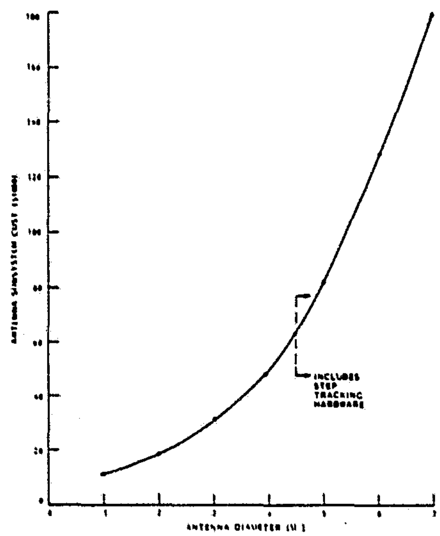

Figure 3.5-2. Antenna Subsystem Costs Vs Diameter

Two major cost elements for all earth station concepts are the antenna and HPA costs. The antenna cost model is given in Figure 3.5-2. For diameters of greater than 4.5 meters, additional step tracking hardware costs are included.

For a given antenna diameter, the HPA power per T1 channel is equal to:

$$P_{HPA/T1} = \log^{-1}_{10} \left\{ [0.1 \right\} \text{EIRP (Table 3.2-18 or Table 3.2-19)} + 20 \log \alpha$$

$$\left[- 46.6 - 20 \log D + 0.07D^2 \right] \qquad \text{Watts}$$

For a TDMA uplink of a given burst rate (BR), in Mbps, the HPA power equals:

$$P_{HPA/BR} = (BR/1.544) \ [P_{HPA/T1}] \qquad \text{Watts}$$

The HPA cost versus power level is a function of power range. For SS-FDMA systems, in which each HPA supports a given T1 channel, the power level is of the order of tens of watts, Helix TWTA's can be utilized and the cost per T1 channel is:

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$$C_{HPA/T1} = 4.572 \quad [P_{HPA/T1}]^{0.43} \qquad \$1000$$

Coupled cavity TWTA's can support hundreds of watts of RF power. TDMA uplinks require powers of 50 watts or greater. The cost of a HPA in that case, for a burst rate BR Mbps, equals:

$$C_{HPA/BR} = 7.7 \quad [(BR/1.544)\ [P_{HPA/T1}]]^{0.387} \qquad \$1000$$

The earth station hardware costs consist of the subsystem equipment plus shelter. The earth station hardware costs are also related to the number of units of a given system produced. The production quantity reduction factor QF is given as a function of number of units in Figure 3.5-3. The additional miscellaneous costs (survey, licensing, etc.) are independent of production quantity or earth station capacity and are estimated to be $13,000 (Section 3.4.2).

The earth station installation costs are assumed to equal 17% of the hardware costs. Therefore, the installed earth station cost is:

$$C_{ES} = 13 + 1.17\ QF\ (\text{Hardware Costs}) \qquad \$1000$$

where QF is defined in Figure 3.5-3.

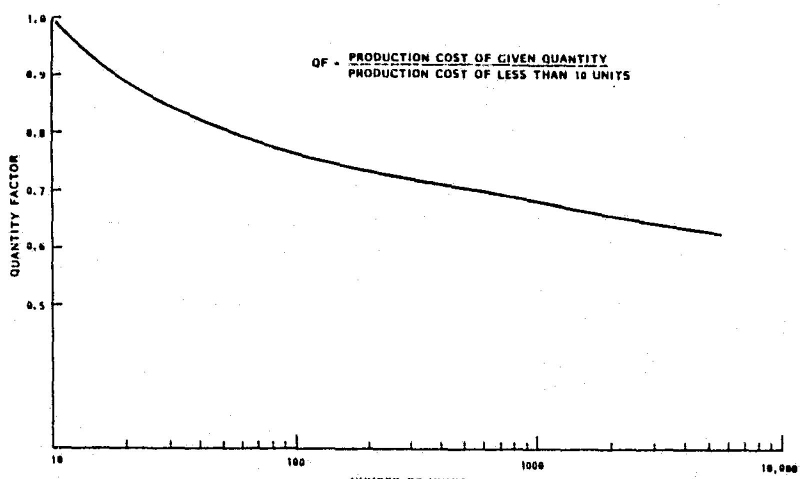

Figure 3.5-3. Production Quantity Factor

Hardware cost models for the various concepts are developed in the next section.

One final consideration in the determination of earth station costs is equipment availability. The non-redundant earth station has an equipment availability of 99.5% (Section 3.2). However, by providing redundancy in the earth station equipment, the equipment availability can be of the order of 99.995% but at a penalty of increased hardware costs. For the case of station diversity, which gives more time for repair of equipment, a non-redundant configuration can be used. The diversity station can be used to provide redundancy as well as site diversity. A redundant configuration is required if station diversity isn't employed.

3.5.3 EARTH STATION INSTALLED COSTS

The earth station configurations and equipment lists are given in Section 3.2 for the following four systems:

SS-FDMA
SS-TDMA Fixed Beam
SS-TDMA/Scanning Beam
HYBRID

In addition to the antenna and HPA costs, which are characterized above, these are the costs in the tables of Section 3.4. These costs have been put into models and used in the trade-off and sensitivity analyses. The models are discussed below.

<u>SS-FDMA Earth Station Equipment Costs</u>

For a SS-FDMA system serving user networks with total capacity of N_{T1} units of 1.544 Mbps each, the earth station hardware costs for non-redundant and redundant configurations are as shown in Table 3.5-1. The total hardware costs for a non-redundant configuration are:

$$C_{EQ/FDMA} = \text{Antenna Cost (Figure 3.5-2)} + 103.5 + N_{T1} \left(C_{HPA/T1} + 8.5\right) \quad \$1000$$

Table 3.5-1. SS-FDMA Earth Station Hardware Costs ($1000)

	Configuration	
	Non-Redundant	Redundant
• **Baseband**		
- T_1 Interface Port Cards	(N_{T1})	$(N_{T1}+1)$
- Redundancy Switchover	-	$1.5\ N_{T1}$
- Other Baseband Components	20.5	41
• **Modulation**		
- T1 Modem	$5\ N_{T1}$	$5(N_{T1}+1)$
- Redundancy Switchover	-	$1.5\ N_{T1}$
- Other Components	15	30
• **IF/RF**		
- HPA (vs D)	$N_{T1}C_{HPA/T1}$	$2\ N_{T1}C_{HPA/T1}$
- Antenna (vs D)	Figure 3.5-2	Figure 3.5-2
- Power Combiner	$2.5\ N_{T1}$	$5\ N_{T1}$
- Other Components	52	104
• Environmentally Controlled Shelter	16	16

For the redundant configuration the total hardware costs are:

$$C_{EQ/FDMA_{(R)}} = \text{Antenna Cost (Figure 3.5-2)} + 197 + N_{TI}\ (C_{HPA/T1} + 14) \quad \$1000$$

SS-TDMA/Fixed Beam Earth Station Equipment Costs

For a SS-TDMA/Fixed Beam system earth station with a total capacity of N_{T1} units of 1.544 Mbps and transmitting at a maximum burst rate of BR Mbps, the earth station hardware costs for non-redundant and redundant configurations are itemized in Table 3.5-2. The equipment costs are similar for both fixed beam and scanning beam SS-TDMA systems with the later having larger burst rates and antenna sizes. In addition, the baseband equipment costs are greater. The scanning beam SS-TDMA earth station hardware costs are given in

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Table 3.5-2. SS-TDMA/Fixed Beam Earth Station Hardware Costs ($1000)

	Configuration	
	Non-Redundant	Redundant
• **Baseband**		
- Split T_1 Port Cards	$3N_{T1}$	$3 (N_{T1} + 1)$
- Redundancy Switchover Unit	-	10
- OtherComponents	15	30
• Burst Modem	BMC (Fig 3.5-4)	2 BMC (Fig 3.5-4)
• Antenna (vs D)	Fig 3.5-2	Figure 3.5-2
• Coupled Cavity TWTA HPA	C_{HPA}/BR	$2\ C_{HPA}/BR$
• Other Components	54	108
• Environmentally Controlled Shelter	16	16

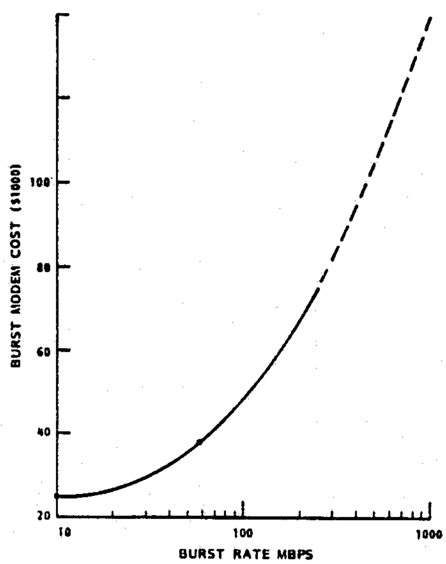

Figure 3.5-4. SS-TDMA Burst Modem Costs

Table 3.5-3. Included in the costs given in Table 3.5-3 is that of the burst modem. The burst modem cost as a function of burst rate is given in Figure 3.5-4.

The total hardware costs for non-redundant fixed beam SS-TDMA configurations are:

$C_{EQ/TDMA-FB}$ = Ant. Cost (Fig. 3.5-2) + BMC (Fig. 3.5-4) + 3 N_{T1} + $C_{HPA/BR}$ + 85 $1000

For the redundant fixed-beam SS-TDMA configuration, the hardware costs are

$C_{EQ/TDMA-FB(R)}$ = Ant. Cos (Fig. 3.5-2) + 2 BMC (Fig. 3.5-4) + 3 N_{T1} + 2$C_{HPA/BR}$ + 167 $1000

For the non-redundant scanning beam SS-TDMA configuration, the hardware costs are:

$C_{EQ/TDMA-SB}$ = Ant. Cost (Fig 3.5-2) + BHC (Fig. 3.5-4) + 3 N_{T1} + $C_{HPA/BR}$ + 185 $1000

Table 3.5-3. SS-TDMA/Scanning Beam Earth Station Hardware Costs ($1000)

	Configuration	
	Non-Redundant	Redundant
• Baseband		
- Split T_1 Port Cards	$3N_{T1}$	$3(N_{T1}+1)$
- Redundancy Switchover	-	20
- Other Components	115	130
• Burst Modem	BMC (Fig 3.5-4)	2 BMC (Fig 3.5-4)
• Antenna (vs D)	Fig 3.5-2	Fig 3.5-2
• Coupled Cavity TWT HPA	$C_{HPA/BR}$	2 $C_{HPA/BR}$
• Other Components	54	108
• Environmentally Controlled Shelter	16	16

For the redundant scanning beam SS-TDMA configuration, the hardware costs are:

$$C_{EQ/TDMA\text{-}SB(R)} = \text{Antenna Cost (Figure 3.5-2)} + 2\ \text{BMC (Figure 3.5-4)} + 3N_{T1} + 2\ C_{HPA/BR} + 277 \text{ -- } \quad \$1000$$

HYBRID Earth Station Equipment Costs

For a HYBRID earth station with a total capacity of N_{T1} and receiving at a maximum rate BR Mbps, the earth station hardware costs for non-redundant and redundant configurations are itemized in Table 3.5-4. The total hardware costs for a non-redundant configuration are:

$$C_{EQ/HYBRID} = \text{Antenna Cost (Figure 3.5-2)} + 10\ (BR/10)^{0.44} + N_{T1}\ (C_{HPA/T1} + () + 87 \text{ -- } \quad \$1000$$

Table 3.5-4. HYBRID Earth Station Hardware Costs ($1000)

	Configuration	
	Non-Redundant	Redundant
• T_1 Port Cards	$1.5\ N_{T1}$	$1.5\ (N_{T1}+1)$
• SMSK Demodulator	$10\ (BR/10)^{.44}$	$20\ (BR/10)^{.44}$
• Antenna (vs D)	Fig 3.5-2	Fig 3.5-2
• HPA (vs D)	$N_{T1}C_{HPA/T1}$	$2\ N_{T1}C_{HPA/T1}$
• Power Combiner	$2.5\ N_{T1}$	$5\ N_{T1}$
• 1.544 Mbps MSK Modulators	$5\ N_{T1}$	$5\ (N_{T1}+ 1)$
• Other Components	71	142
• Environmentally Controlled Shelter	16	16

The total costs for a redundant configuration are:

$$C_{EQ/HYBRID(R)} = \text{Antenna Cost (Figure 3.5-2)} + 20\,(BR/10)^{0.44} + N_{T1}\,(2\,C_{HPA/T1} + 11.5) + 164.5 \text{ -- } \quad \$1000$$

3.5.4 ANNUAL COST FACTORS

The annual costs can be obtained from the installed costs given in the above equations by determination of the cost factor. The cost factor, Fo, defined as the ratio of annual service charge, I, to initial investment, Po, is:

$$F_o = \frac{I}{P_o} = \frac{1}{1-TR}\left[\frac{i\,(1+i)^{T_o}}{(1+i)^{T_o}-1}\right] - \left[\frac{TR}{(1-TR)}\right]\frac{1}{T_o} - K]$$

where

i	=	return on investment
TR	=	tax rate
T_o	=	ground network lifetime
K	=	yearly expenses/P_o

The above assumes a payback per year

$$\text{Payback per Year} = P_o\left(\frac{i\,(1+i)^{To}}{(1+i)^{T_o}-1}\right)$$

A depreciation rate P_o/T_o and yearly operating expenses of KP_o are also assumed. F_o is derived from payback per year = (I - taxes - KP_o), where taxes = TR (I - P_o/T_o - KP_o). Assuming a tax rate of .46 and a value of K = 0.15, the annual charge factor F_o is as listed in Table 3.5-5 for different rates of return on investment and lifetime. The annual charge factors for the ground network vary from 0.4 to 0.6. The yearly operating expense is assumed to be 15% of the installed costs. Operation and maintenance strategies are discussed in Section 3.5.6.

Table 3.5-5. Annual Charge Factor For Ground Segment

	ANNUAL CHARGE FACTOR F_0*		
Return On Investment	.15	.17	.2
LIFETIME			
5 YEARS	.531	.55	.599
10 YEARS	.434	.462	.507
15 YEARS	.410	.441	.489

*BASED ON TAX RATE = .46
YEARLY EXPENSE = 15% INITIAL INVESTMENT

3.5.5 MINIMIZATION OF THE COST OF INSTALLATION AND CHECKOUT

In any network designed to distribute CPS traffic, it is expected that a large number of earth stations are going to be included in the network. An opportunity, therefore, exists to trim a great deal of cost from the installation and integration process. The ideal procedure for installation and integration of a network comprised of a large number of earth stations will depend upon the number of sites, their geographic distribution and the number of contractors involved, but it will always fall between the following two extremes:

1. All components are assembled at the plant of the prime contractor for factory integration and checkout; the assembled earth station is then shipped to the site for installation..

2. All components are shipped to the site for integration and checkout, thereby bypassing the factory integration procedure.

A more workable solution could be devised in each particular case, based upon the following example. All baseband and IF components are first assembled in racks at the prime contractor's site. Any subcontracted components therein are thus shipped to the prime contractor's location. The integrated and tested baseband and IF racks are then shipped to the shelter vendor's plant for installation in the environmental shelter. Any stand-alone components

which need to be included in the shelter (e.g., power line isolation transformers and air conditioning units) may be shipped directly to the shelter vendor's plant.

Concurrently, the major contractor involved with the integration of the RF/Antenna subsystem should be the recipient of all subcontractor outputs relevant to that subsystem. Installation and integration of these elements are performed at that contractor's factory location. Prior to the shipment of any integrated hardware, the CPS site must be fully prepared, in terms of the provision of appropriate local building permits, frequency clearances for FCC licensing, grading, concrete pads, and other necessary civil works, antenna anchor hardware and provision of Prime power, running water, and other necessary utilities.

Upon delivery of the shelter and antenna subsystems to the CPS site, the prime contractor's integration team should be dispatched to the site. This team will provide final assembly and complete station testing. Automated test equipment and a dedicated satellite channel will expedite this process and isolate the network from mishaps due to faulty hardware in the new CPS station. Figure 3.5-5 depicts this hybrid approach to earth station installation and checkout.

3.5.6 OPERATION AND MAINTENANCE STRATEGIES

The operation and maintenance guidelines outlined in this section are designed to provide superior telecommunications service to CPS customers. A highly trained technical staff to implement the following procedures is the most important aspect of the successful operation and maintenance strategy. Structure and discipline in the operation program leads to more efficient and reliable service offerings. Routine maintenance procedures need to be performed in order to minimize system failures. Finally, detailed plans of action need to be drawn up which indicated necessary steps to be taken in the event of component failures.

Operation

Of prime importance to reducing the cost of CPS services is unmanned operation. The area around t earth station should be enclosed by a security fence to control access. The shelter housing the CPS station should be environmentally controlled, as it will house the high power amplifiers,

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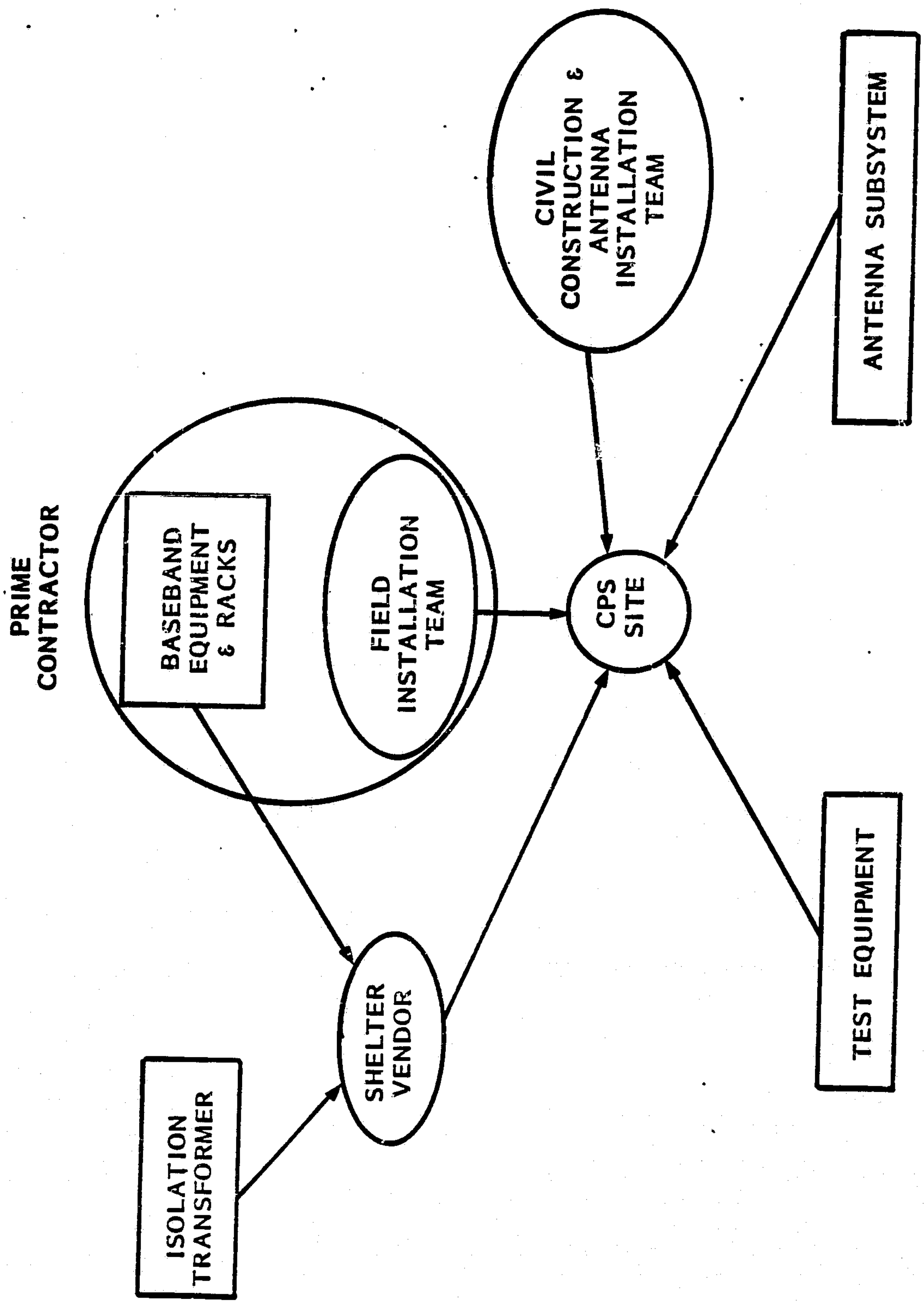

Figure 3.5-5. Minimizing Installation and Checkout Costs

transmit waveguide switching equipment, motorized antenna control equipment, exciters, video receivers and receive/transmit equipment. Extension meters should be provided at this position to monitor the high power amplifier power output levels, VSWR, and temperature, and to provide equipment fault alarms. Extension controls to allow activation and deactivation of the transmitters should also be provided. Since the antenna controls, receivers, and transmitters will all be located in the shelter, maintenance personnel will be able to monitor all operating parameters, including frequency, modulation and energy dispersal, in addition to the HPA output levels. A status and fault alarm panel shou , be provided to monitor redundant systems and to allow for manual override or control of the system. Closed circuit television monitoring of the CPS site is also recommended as a safety precaution.

Antenna elevation and azimuth must be verified on a regular schedule, particularly in fixed pointing systems. Prior to transmitter activation, antenna orientation should be further verified by observing receiver AGC levels.

Maintenance

The maintenance requirements for a CPS earth station fall into three general categories: Routine maintenance, fault isolation, and fault analysis and repair. Routine maintenance includes those activities, performed on a periodic basis which are geared toward prevention and early detection of operational failures. Fault isolation provides procedures that are intended to identify and localize the cause of a failure. Fault analysis and repair consists of measurement and evaluation procedures to determine the exact cause of a failure and the corrective action required to remedy the cause. All equipment vendors should provide documentation of maintenance procedures as well as instructions for removal and replacement of equipment units.

Routine maintenance procedures are performed periodically to clean and inspect the CPS earth station. The purpose of these procedures is to reduce common types of failures, such as overheating due to clogged air filters, for example. By performing these procedures, the technician also develops a familiarity with the equipment which may enable him to detect a potential operational failure before it causes a system inte uption. In general, these procedures should be performed every three months. Visual inspection of the earth station equipment includes the following:

1. Inspect shelter interior. Remove any trash and unauthorized material from floor and from tops of equipment cabinets.

2. Check intake and exhaust areas of cooling/heating units for obstructions.

3. Check exhaust fan outlets for obstructions, such as birds' nests, leaves, etc., and remove.

4. Inspect all cabling and cable connectors. Ensure that connectors are firmly seated. Check cables for damage to insulating material.

5. Check cable entry/exit from control room to ensure that weather-proofing is secure.

6. Check equipment cabinet doors and access covers. Make sure that they are in place and secure.

7. Inspect and operate all back-up generation and cooling.

Even with a rigorous routine maintenance program, electronic components do indeed fail and the other two categories of maintenance procedures are used in response to such failures. It is imperative that the cause of equipment failure be isolated as rapidly as possible so that technicians may be dispatched to replace the failed module. Fault isolation procedures should be presented in the form of flowcharts. These flowcharts are used to guide the technician from a fault symptom, through a logical testing algorithm, to one or more probable causes. In addition to such flowcharts, vendor documentation for each component should include theory of operation, modular breakout of Field Replacable Units (FRUs), parts list, critical performance parameters, test points and waveforms, software diagnostics package and FRU removal and replacement procedures.

Automated maintenance records can greatly facilitate the adequate provisioning of spares, identify latent equipment design flaws, and contribute to the increased reliability of the network. Such automated records should include history by location, history by part serial number and category, repair log and inventory control.

In addition, a thoroughly planned repair procedure should be followed in order to obtain the highest practical level of system availability. The essential points include the following:

1. Diagnostics. All equipment should be testable, both locally and remotely, in order to assess proper operation. Faults should be indicated to the FRU (Field Replaceable Unit) level.

2. Module Level Repairs. All equipment should be capable of field repair by means of module replacement. Its design should minimize the need for any periodic maintenance actions.

3. System Control. A failed unit must be prevented from disrupting the operation of the network as a whole.

4. Field Force. The service group which will be responsible for earth station, and regional communications equipment should be controlled by a single central service organization.

5. Training. Training of field repair force personnel should be the responsibility of this centralized organization, which should also produce and maintain complete sets of documentation on equipment, interfaces, repair procedures, and troubleshooting.

6. Local Spares Depot. When a module fails, it will be replaced with a spare module from the local spares depot. This depot should maintain inventories of all module types in sufficient quantities so that there is 95% probability of finding a suitable spare, given the module population as a function of time. All failed modules should pass through the local spares depot for logging before they are forwarded to the Repair Depot.

7. Repair Depot. All failed modules which are replaced in the field should be returned to a conveniently located facility for repair. This facility should operate with the goal of one-day turn-around for 90% of modules. The repair facility may be centrally located, or may be centrally located, or may be geographically dispersed at various vendor locations, as appropriate.

3.6 ANNUAL COST OF GROUND NETWORKING

The analyses of CPS ground networking annual costs are discussed in this section. The ground network consists of the terminations at the earth station network concentrator and all interconnecting links including backup links in the case of diversity operation.

The approach taken is to relate network characteristics versus area of ground network coverage. An analysis of urban sections of major metropolitan areas of the nine CONUS regions gives both a range of urban areas and an average area which typifies the CPS ground network coverage. In this typical area, the number of user facilities versus availability is determined.

A simple model for ground networking is utilized to determine the number of links, link lengths and link capacities versus user group in the typical area (scaleable to other areas). The additional networking requirements to provide outage backup (diversity) are defined. From the number, length and capacity of the networks, the network installed costs are determined.

3.6.1 COVERAGE AREA CHARACTERISTICS

The coverage area for the CPS earth stations in any metropolitan region is assumed to be principally located within the urban area. A list of the urban land area of nine major metropolitan areas for the nine major CONUS regions is given in Table 3.6-1. The average area of these nine metropolitan areas is 566 sq. km (218.6 sq mi). This average area is used to typify a CPS network coverage.

The number of CPS facilities is given in Section 2.3 for the various user groups and system availabilities. For the case of CPS with an availability 99.5%, it is assumed that the maximum year 2000 aggregate peak capacity is 5 Gbps. This also assumes CPS service can be provided at reduced costs. Rain outage backup can be provided by a combination of power margins and forward error correction and diversity networks. For the case with an availability of 99.9%, it is assumed that the CPS cost is competitive with other services and that the maximum peak aggregate traffic is 5 Gbps for the year 2000.

The number of facilitie· ,er metropolitan area vs. user group and availability is given in Table 3.6-2. For all user groups except Federal Agency and Large State/City Agency, the facility density data given in Section 2.4 times the

Table 3.6-1. CPS Ground Networking Coverage Areas

CONUS Region	Metropolitan Area	Land Area (sq. km)
New England	Boston, MA	119
Middle Atlantic	New York City	776
East North Central	Chicago, Ill	577
West North Central	St. Louis, Mo	159
South Atlantic	Atlanta, GA	341
East South Central	Louisville, KY	155
West South Central	Houston, TX	1124
Mountain	Phoenix, Ariz	642
Pacific	Los Angeles, CA	1201
	Overall Average	566

metropolitan urban area listed in Table 3.6-1 is used to obtain number of facilities in a given region.

It is also assumed that each of the major cities listed has a single Federal Facility and a large state/city agency facility. The municipality CPS user group is not included in the listing of major cities.

The number of facilities is rounded off in integers in determining the number of facilities in a typical metropolitan area. It is assumed that the number of facilities in Table 3.6-2 represent those within the typical CPS coverage area (566) sq km).

3.6.2 GROUND NETWORK CONFIGURATIONS

In the analysis of ground networking, it is assumed that the user facilities listed in Table 3.6-2 for any metropolitan region are uniformally distributed over the area. If there are "n" earth stations in the netropolitan area (A), then the coverage area of each earth station is A/n based on the uniform distribution assumption. It is further assumed that the extent of coverage is based on a circular area (A/n) giving a coverage radius r_e per earth station of $r_e = \sqrt{A/n\pi}$.

Table 3.6-2. Number of User CPS Facilities

User / Area	Average 99.5% 5 Gbps Peak Aggregate Capacity					Average 99.9% 5 Gbps Peak Aggregate Capacity				
	Large Bus.	Medium/ Small Bus.	Govt. Agencies	Institutions	Private Homes & Condos	Large Bus.	Medium/ Small	Govt. Agencies	Institutions	vate # Homes & Condos
Boston, MA	2	3	0	1	0	4	6	1	1	1
New York, NY	18	30	1	4	1	49	72	3	13	3
Chicago, IL	8	13	1	2	1	21	31	2	6	2
St. Louis, MO	2	3	0	1	0	4	6	1	1	1
Atlânta, GA	1	2	0	1	0	3	5	1	1	1
Louisville, KY	1	2	0	1	0	2	4	1	1	1
Houston, TX	3	5	1	1	0	8	12	1	2	1
Phoenix, AR	2	3	0	1	0	4	6	1	1	1
Los Angeles, CA	7	10	1	2	1	17	26	1	5	1
AVERAGE *	5	8	1	2	0	13	19	1	4	1

Year 2000

* # groups of 1000 units

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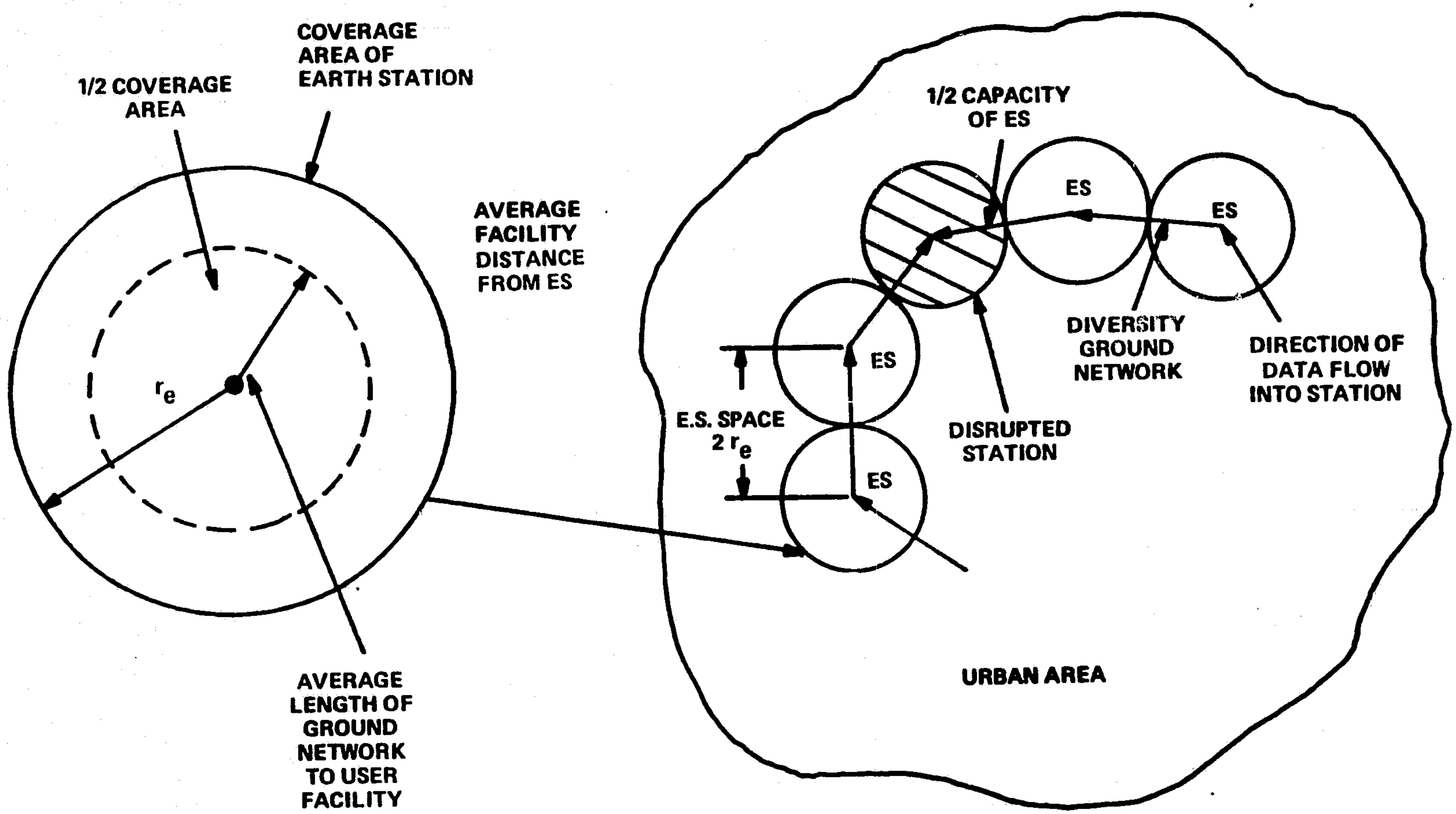

Figure 3.6-1. Ground Network with Diversity

It is also assumed that the average length, r_{avg}, of the ground network within the earth station coverage area, A/n, corresponds to one-half the coverage area, or $r_{avg} = r_e/\sqrt{2}$.

For the case of the typical area of 566 sq. km (218.6 sq. mi) the coverage radius and average network length are ;8.3/ $\sqrt{2}$ miles and 5.9/ $\sqrt{m}$ miles, respectively.

Most user groups will utilize all of the offered CPS services: voice, video conferencing, video information, computer message and computer data. The exceptions are Businesses, which are not projected to use CPS video information services, and private homes and condominiums, which are not projected to utilize CPS video conferencing and computer message services (Section 2.3).

Based on the peak capacity per user facility as given in Section 2.3, the maximum throughput per user (normalized in T_1 units) versus user and CPS service are given in Tables 3.6-3 and 3.6-4 and for availabilities of 99.5% and 99.9%. The total network capacity and the total earth stations capacity are also listed.

Because of the very small anticipated expenditures of individual private homes and condominums, it is assumed that all such units in the metropolitan area are concentrated by some network. Such networks are not considered as part of the CPS ground network. The private user would incur the additional concentration network charges. For example, existing CATV networks could be used to concentrate the CPS service to private users.

A promising method of providing rain outage backup is to interconnect several or all earth stations in an area and utilize non-affected Earth Stations to support the traffic required by the affected coverage area through the interconnecting ground network. The computation model for a ring configuration of the interconnect is shown in Figure 3.6-1. An earth station can be used to provide diversity provided it is spaced greater than 6 miles from the adjacent to station. Thus, for a region with n earth stations, the number of stations that can provide diversity throughput to disrupted stations is:

Table 3.6-3. Ground Network Capacity Requirements: **Year 2000**
Availability 99.5% Capacity 5 Gbps

User Class	Number Facilities	Voice	Maximum Throughput/User-T_1 Lines				Per User Total T_1 Lines	User Class Total T_1 Lines	User Class Share of E.S. Mbps
			Video Conf.	Video Info.	Comp. Message	Comp. Data			
Large Business	5	1.5	2	0	.11	.16	4	20	29
Medium/Small Business	8	.25	0	0	.036	.031	1	8	3.92
Large Government Agencies	1	2.1	2	4	.18	.31	9	9	13.2
Institutions	2	.66	2	4	.10	.16	7	14	21.4
*Private Homes *Condominiums	0								

Coverage Area 566 Sq. Km

*Assume used with existing concentration networks (1000 units)
Total Network: 51 T1 Lines
Total Regional Earth Station Capacity: 67.5 Mbps

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Table 3.6-4. Ground Network Capacity Requirements: Year 2000
Availability 99.9%, Capacity 15 Gbps

User Class	Number Facilities	Voice	Maximum Throughput/User-T_1 Lines Video Conf.	Video Info.	Computer Message	Computer Data	Per User Total T_1 Lines	User Class Total T_1 Lines	User Class Share of E.S. Mbps
Large Business	13	2.1	2	0	.11	.16	5	65	87.1
Medium/Small Business	19	.33	0	0	.04	.04	1	19	11.8
Large Government Agencies	1	3.2	2	4	.2	.3	10	10	14.9
Institutions	4	.83	2	4	.1	.07	7	28	44
*Private Homes	1	2.07	0	4	0	.06	7	7	9.5

Coverage Area 566 Sq. Km

Coverage Area 566 Sq. Km
Total Newtork: 129 T1 Lines
Total Regional Earth Station Capacity: 167.3 Mbps
* Assume used with existing concentration newtorks (1000 units)

For $2r_e > 6$ miles; n - 1

For $2r_e < 6$ miles; n - 1 - M

Where M = number of stations adjacent to and within 6 miles of the disrupted station.

In the analysis, it is assumed for the case when the spacing between earth stations is less than 6 miles, the maximum number of earth stations excluded from providing throughput is two. However, it is assumed that these adjacent stations have enough fade margin to provide output to their coverage area. In the ring network arrangement,it is also assumed that each non-affected earth station shares equally in the diversity load and the flow of traffic is symmetrical. Therefore, for the network configuration shown in Figure 3.6-1, the maximum diversity line capacity (for $n > 2$) is equal to 1/2 the earth station capacity. For the case of two earth stations in a region, the full capacity must be provided by the diversity network. The characteristics of the diversity network for the typical region (area = 566 sq km) are summarized in Table 3.6-5. That table provides the data for the length and capacity (normalized to T1) of the diversity network utilized in the costing model. Also of significance is the requirement to increase earth station capacity in order to have the margin required to support faded station traffic. The earth station capacity requirements are also indicated in Table 3.6-5.

The diversity network must include provisions for switchover in that the sites are receiving identical bit streams but the streams are not in time phase because of the different distances to the satellite. Similar considerations apply to the transmission. The switchover circuits must compensate for the time phase differences if hitless switchover is to be provided. The hitless switchover requirements for the diversity network are discussed in Section 3.1. The cost analysis neglects the above switching costs.

3.6.3 GROUND NETWORK COSTS

The capacity, length, number of lines and network configuration has been characterized in Section 3.6.2 for a typical region as a function of number of earth stations within the region. The network cost depends on all of these factors. In Section 3.1, the cost of a network has been estimated as a function of length for three different transmission modes: point-to-point microwave radio, fiber optic cable and dedicated routed coaxial cable. These

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Table 3.6-5. Diversity Network Characteristics

NUMBER OF EARTH STATIONS	LINE LENGTH (MILES)	DIVERSITY LINE CAPACITY (T1)	NUMBER OF DIVERSITY EARTH STATIONS	EARTH STATION OVER-DESIGN FACTOR	EARTH STATION CAPACITY (Mbps)
2	11.8	55	1	2	168
3	9.63	19	2	1.5	84
4	8.34	14	3	1.33	55.9
5	7.46	11	4	1.25	42
6	6.81	10	5	1.2	33.6
7	6.3	8	6	1.17	28.1
8	5.9	7	5*	1.2	25.2
9	5.6	6	6*	1.17	21.8
10	5.3	6	7*	1.14	19.2

YEAR 2000
AVERAGE URBAN AREA (566 Sq km)
AVAILABILITY $\geq$ 99.9%
AGGREGATE PEAK CAPACITY 15,000 MBPS
*SPACING BETWEEN ADJACENT STATIONS TOO SMALL TO PROVIDE DIVERSITY CAPACITY

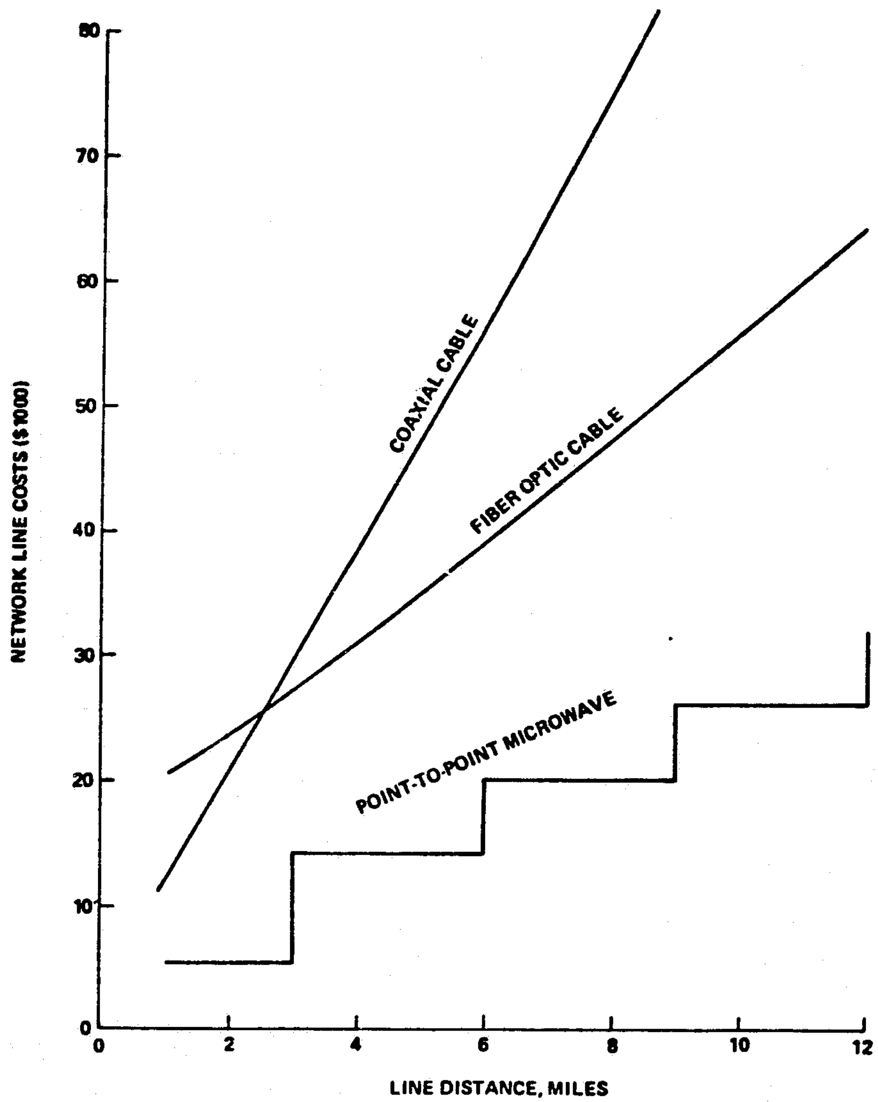

Figure 3.6-2. Installed Cost of Ground Networks vs. Transmission Mode

costs are summarized in Figure 3.6-1. In addition to these length dependent costs, there are costs incurred at the earth station network concentrator which are (Section 3.1):

	Fixed Cost Dollars	Cost Per Circuit Dollars
T1 Point-to-Point Microwave Video	5,000	16,000
T1 fiber optical cable	5,000	17,000
T1 coaxial cable	5,000	1,000

In the cost analysis it is assumed that only one of the above type transmision modes is utilized for all links. The ground network costs are equal to the total number of lines (in T1 units) utilized times the cost per line (which is length dependent) plus the network concentrator costs. The line costs for a region of area A:

$$\text{Line Costs} = P_t\,(r_{avg}) \sum_{i=1}^{k} N_{t_i}\, d_i A$$

where

$P_t\,(r_{avg})$ = cost per line of transmission mode (radio, fiber optics, coax cable Figure 3.6-2)

$r_{avg} = \sqrt{A/2n\pi}$

N_{t_i} = number of T1 equivalent lines per facility of user group "i" (Tables 3.6-3 and 3.6-4)

d_i = facility density of ith user group

$d_i A$ = number of facilities in area A of ith user group

k = number of user groups

The network concentrator costs equal the fixed costs per concentrator times the number of concentrators (assumed equal to the number of earth stations, n) plus the costs per circuit times the number of circuits.

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The network concentrator costs equals:

$$\text{Network Concentrator Cost} = \$5000\ n + P_c \sum_{i=1}^{k} N_{t_i} \quad d_i A$$

where

n = Number of earth stations

p_c = Cost per circuit (listed above)

The diversity network cost is equal to the number of diversity network equivalent T_1 lines times the cost per line (function of spacing between earth stations $2r_e$) plus the terminal costs which are assumed equal to the network concentrator costs. For an area of total capacity C_T (Mbps) with n earth stations, the diversity network costs are:

For n = 2

$$\text{Diversity costs} = \frac{C_T}{1.544} [P_t\ (2r_e) + P_c] + \$10{,}000$$

where

$r_e = \sqrt{A/2\pi}$

For $n > 2$

$$\text{Diversity Cost} = \frac{C_T}{3.088} [P_t\ (2r_e) + P_c] + \$5000\ n$$

where

$r_e = \sqrt{A/n\pi}$

Utilizing the costing procedure described above, the network line costs without diversity backup are given in Table 3.6-6 for a typical region of 566 sq km as a function of number of earth stations and transmission mode for system availabilities of 99.5% and 99.9%. For most of the range of number of earth stations, there is little difference between costs for the microwave and coaxial cable links which are optimum for ground networking (the former limited by saturation of bandwidth).

Table 3.6-6. Year 2000 Ground Networking Costs: No Diversity ($1000)

Coverage Area = 566 sq km (218.6 sq. mi)

No. Earth Sta.	Avg. Network Length Miles	Capacity 5000 Mbps Availability 99.5% , N_T=51			Capacity 15,000 Mbps Availability 99.9% , N_T=129		
		Micro Radio	Fiber Optic Cable	Coax Cable	Micro Radio Cable	Fiber Optic	Coax Cable
1	5.9	1841	2912	2963	4649	7358	7487
2	4.17	1539	2560	2152	3880	6460	5428
3	3.41	1545	2361	1800	3885	5949	4530
4	2.95	1550	2264	1601	3890	5696	4019
5	2.64	1146	2218	1402	2863	5572	3508
6	2.41	1151	2172	1305	2868	5448	3255
7	2.23	1156	2125	1259	2873	5324	3131
8	2.09	1161	2131	1162	2878	5329	2878
9	1.97	1166	2136	1167	2883	5334	2883
10	1.87	1171	2141	1172	2888	5339	2888

The diversity network costs and total network costs with diversity are summarized in Table 3.6.3-2 based on the diversity network characteristics given in Table 3.6.2-3. (area = 566 sq. km, availability = 99.9%). The switching costs are neglected in Table 3.6.3-2. Because of the longer length of network in the diversity lines, the microwave radio transmission mode shows a clearcut advantage when compared to the fiber optics and coaxial cable links.

Table 3.6-7. Year 2000 Ground Networking Costs with Diversity ($1000)
Coverage Area = 566 sq. km (218.6 sq mi)
Availability 99.9%

Number of Earth Stat.	Diversity Link Costs*			Total Network Costs		
	MW Radio	Fiber Optic	Coax Cable	MW Radio	Fiber Optic	Coax Cable
2	2650	4410	6060	6530	10870	11488
3	2409	4119	5202	6294	10068	9732
4	2036	3716	4444	5926	9412	8463
5	2005	3490	3930	4868	9062	7438
6	2190	3630	3830	5058	9078	7185
7	2051	3283	3450	4924	8607	6705
8	1720	3232	3232	4598	8561	6110
9	1665	3015	2961	4548	8349	5844
10	1850	3310	3150	4738	8649	6038

*Costs for switching subsystem not included.

3.6.4 ANNUAL GROUND NETWORK COSTS

The determination of the annual cost factor is given in Section 3.5.4. Based on the discussion given in Section 3.1, an annual operating expense for the ground network is 15% of the initial installation costs of the network. For a ground network life of 15 years and a 20% return on investment, the annual charge factor, Fo, for the ground network from Table 3.5-5 data is 0.489.

Based on the data of Tables 3.6-6 and 3.6-7 and the above charge factor the ground network annual costs are compared in Table 3.6-8 for the conditions of minimum cost for the average urban area.

The minimum cost results when the number of earth stations range from five to ten. The costs presented in Table 3.6-8 are normalized per T_1 channel. A comparison is given with Telco costs based on Table 3.1-23 data converted to annual costs and to a T_1 channel. The Telco costs are significantly higher.

Table 3.6-8. Year 2000 Ground Networking
Annual Costs per T_1 Channel ($1000)

Case	Microwave Radio	Fiber Optics	Coaxial Cable
• Availability 99.5% - No Diversity (5000 Mbps)	11	20.4	11.2
• Availability 99.9% - No Diversity (15,000 Mbps)	10.9	20.2	10.9
• Availability 99.9% - Diversity (15,000 Mbps)	18	31.6	22.2
• TELCO	99.5		

Average Urban Area = 566 sq km
Minimum Costs for Table 3.6-6 and 3.6-7.

SECTION 4

TASK 3 - DEFINITION OF THE SPACE SEGMENT FOR THE SATELLITE SYSTEM

SECTION 4

TASK 3 - DEFINITION OF THE SPACE SEGMENT FOR THE SATELLITE SYSTEM

In this section the satellite payloads for the four types of system are developed in parametric form from which the spacecraft weight and power requirements can be developed. Parametrs include the postulated traffic and the design parameters of number of satellite beams, earth station antenna diameter and whether or not earth station spatial diversity is employed in the system.

A space segment costing procedure, based on the payload weight and power requirements, is defined. The procedure uses the SAMSO, January 1981, cost models.

A spacecraft concept is developed to explore the feasibility of the required spacecraft.

4.1 SATELLITE PAYLOADS

This section contains a description of payload models applicable to the Customer Premise Service (CPS) Concept. As described herein, the CPS system employs Multibeam Antennas (MBAs) capable of providing complete coverage of the contiguous 48 states. In the SS-FDMA configuration, both preassigned and switched channels are employed in a highly channelized payload design that makes use of three levels of bandwidth quantization, equivalent to a single T1 carrier, four T1 carriers and 26 T1 carriers.

In the two SS-TDMA concepts examined, frequency division multiplexing of the TDMA uplinks and downlinks as used to minimize the earth station requirements. Payload weight and power are derived parametrically in terms of the number of antenna beams and the aggregate data rates. Extrapolation to other rates and antenna configurations may be accomplished by the use of design equations that express the power and weight requirements as functions of antenna complexity and data rate. Similarly, the payload for the HYBRID system is developed.

4.1.1 SS-FDMA PAYLOAD

Satellite Switched Frequency Division Multiple Access (SS-FDMA) is an adaptation of conventional FDMA to a satellite having a multiple beam

antenna. SS-FDMA makes use of fixed multiple antenna beams, FDMA channelization, on-board switching for the purpose of bandwidth reallocation, power diversity for fade compensation and conventional (but modified) SCPC/DAMA signalling and switching through a Common Signalling Channel to a centralized Network Control Center. This simplifies and results in relatively low-cost Earth stations. Potential optimization concepts involve beam combining to minimize the channelization and switching requirements, linearized amplifiers to reduce intermodulation distortion and to conserve satellite power, and multi-mode amplifier operation to minimize the RF power required in each beam.

Routing through such a satellite (uplink beam to downlink beam) is determined by a signal's position in frequency; changing the frequency changes the downlink beam. The multiple beam antennas will provide multiple contiguous beams covering the entire service area. Frequency reuse will be used since it provides higher satellite capacity while the associated higher antenna gain also reduces earth station EIRP and G/T requirements.

The satellite payload design is characterized by channelizing filters that determine the routing switch port accessed and the bandwidth of the beam routing, which makes possible matching the available bandwidth to the traffic demand. A linearized transmitter is also required to control intermodulation products.

Signalling and frequency assignment to set up the connections between earth terminals is accomplished via a Common Signalling Channel (CSC) network. The operating mode of the CSC is set up by the Network Control Center (NCC). Signalling emulates that of the terrestrial system and can be designed to interface the satellite system into terrestrial facilities of comparable performance. The NCC actually performs the functions of a telecommunications switch, routing calls, billing, rendering operator assistance, busying out, tracking traffic intensity and assigning frequencies, bandwidth and earth station EIRP. These functions are accomplished automatically by processor in the NCC.

SS-FDMA Payload Diagram

The simplified payload diagram of Figure 4.1-1 demonstrates the architecture of a fixed beam SS-FDMA system. It incorporates separate receiving and

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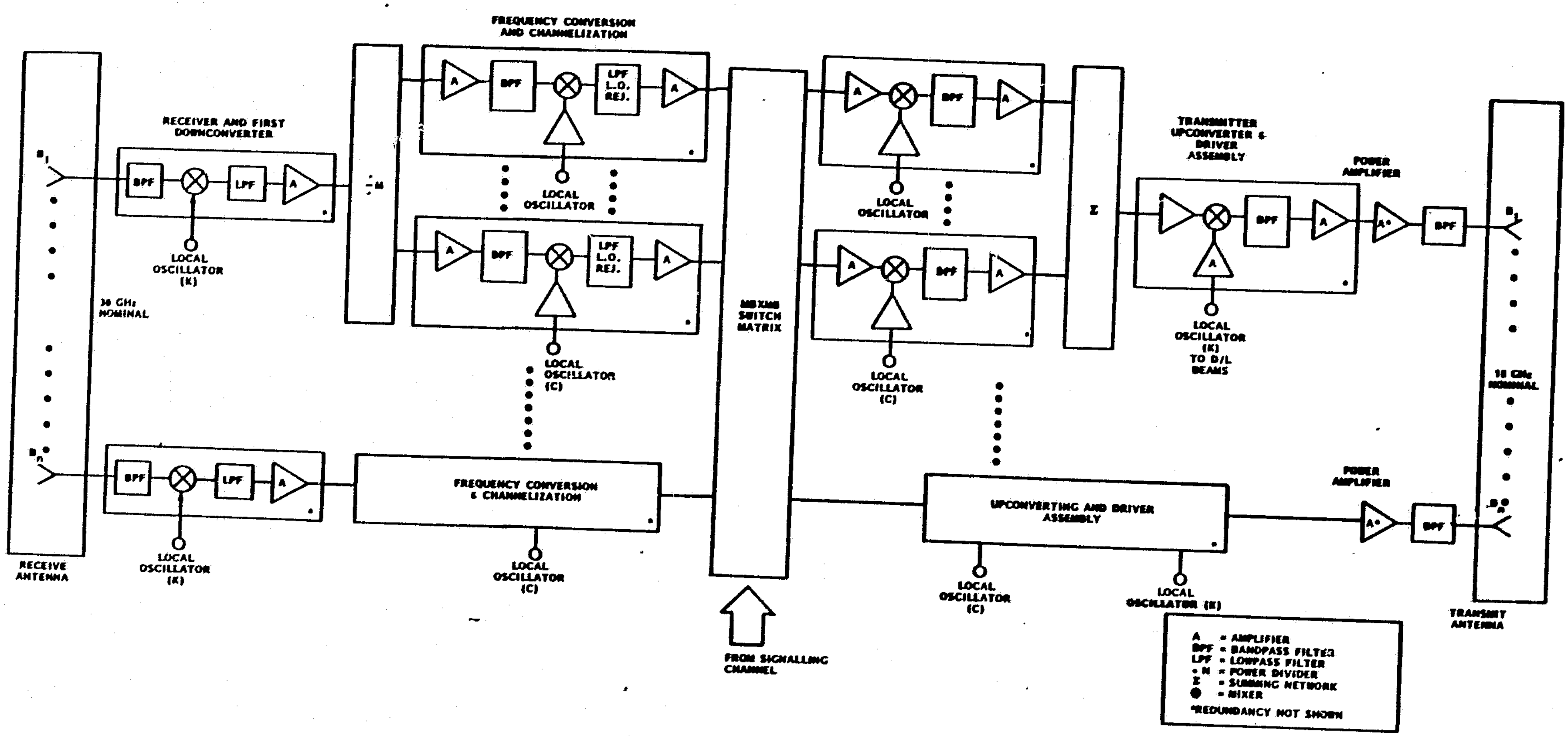

Figure 4.1-1. Simplified SS-FDMA payload Diagram

transmitting antennas with independent beams. When the number of antenna beams becomes large, some economies in hardware can be achieved by combining beams that are only lightly loaded with traffic. The generic fixed beam FDMA model, however, does not require a corporate feed network: Separate fully redundant receivers and downconverters can be utilized on each beam and should be placed as close as possible to the feed horns to preserve the satellite G/T. Similarly, separate transmitters and upconverters are assigned to each beam.

The outputs of the first two downconverters are power divided, undergo further downconversion and are channelized into 10 MHz and 40 MHz channels. 60% of the bandwidth of each beam is separated into 10 MHz channels while 40% of the bandwidth is used in 40 MHz channels. Each channelizing section is fully redundant and the beams are channelized into M channels. The total capacity of the FDMA switch matrix and the total number of converters and channelizing circuits must be consistent with the available RF spectrum bandwidth and the selected frequency reuse plan. The total available RF spectrum bandwidth is assumed to be 1500 MHz and the nominal frequency reuse factor is 1/4, leading to an average spectrum assignment per beam of 375 MHz. Since the geographical distribution of traffic is not uniform, the frequency plan can be modified on a regional basis so long as the adjacent coverage areas do not overlap in frequency. Reuse of the available operating bandwidth provides an effective system bandwidth that exceeds the allocated system bandwidth.

The effective system bandwidth is given by the expression,

$$B_{eff} = N x B x U$$

where N is the number of antenna beams

B is the allocated system bandwidth

U is the frequency use factor.

For instance, a 100-beam system having an allocated system bandwidth of 1500 MHz with a frequency use factor of 1/4 has an effective system bandwidth of 37,500 MHz. In general, the number of beams, N, must be made large enough so

that the required traffic capacity and, hence, bandwidth in any beam is at least equal to or smaller than BxU. Otherwise, the required spatial separation between co-frequency beams cannot be achieved.

Each input beam has connectivity to an output beam as directed by the Common Signalling Channel (CSC) and the Network Control Center (NCC). Appropriate switching trades are discussed later in this Section.

Upconversion uses the same local oscillators as used for downconversion in the receivers. Since angle modulation will be employed, oscillator phase noise will be a concern. The bank of crystal oscillators used to stack the receive channels in frequency across the available bandwidth are also used for the transmitters with an intermediate frequency conversion. Details of the downconversion and upconversion plan are discussed below.

Payload hardware utilization is defined in Table 4.1-1, the SS-FDMA Hardware Utilization Matrix. This matrix summarizes the application, quantities, weight and power requirements of the major payload items. In addition, the matrix describes an overall redundancy plan that is consistent with a highly reliable and long-lived payload.

4.1.1.2 Distribution Of Traffic

In this section traffic models are established for use in parametric studies of various satellite and ground system approaches and configurations. Details of the satellite payload configurations are developed for selected traffic models to the point where weight and power requirements can be evaluated. Parametric relationships between data rates and antenna coverage patterns (number of beams) are derived from this evaluation.

4.1.1.2.1 Communications Traffic Data Rates and the Distribution of Traffic

The communications traffic of interest originates and terminates in the Continental United States (CONUS), excluding Alaska. The satellite design is driven by the peak, or busy hour composite (aggregate) traffic rate expected in the years of 1990 to 2000. Because predictions of traffic rate for this new type of service are subject to uncertainties in the underlying assumptions as well as variations in the estimates of the potential CPS customer base, the Space Segment Study is parameterized over a wider range of peak traffic rates than the current expectation suggests. Payload designs corresponding to peak

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Table 4.1-1. SS-FDMA Hardware Utilization Matrix

PAYLOAD ITEM	QUANTITY REQUIRED	REDUNDANCY	UNIT WEIGHT (POUNDS)	UNIT POWER (WATTS)
RECEIVE ANTENNA	1	NONE	VARIES WITH NO. OF BEAMS	Varies with No. of Beams
RECEIVERS, FIRST DOWN-CONVERTERS	1/BEAM	1:1*		0.75 (Part of Rec. Antenna)
SECOND DOWNCONVERTERS	1/BEAM	1:1*	0.95	0.8
THIRD DOWNCONVERTERS	1/BLOCK	1:1*	0.743	0.6
CHANNELIZING UNITS	.077 x DATA RATE	1:1*	BL_{10} = 6.35; BL_{40} = 3.2	0.9 (ACTIVE ONLY)
LOCAL OSCILLATORS	6 + 2 COMB + (BLOCKS/BEAM)	1:1*	VARIES WITH NUMBER OF BEAMS AND NUMBER OF CHANNELS	
SWITCH MATRIX	1	33% WRAP-AROUND	0.623×10^{-3} PER CROSSPOINT	1×10^{-2} PER CROSSPOINT
TRANSMITTER CHANNELIZING UNITS	.077 x DATA RATE	1:1*	BL_{10} = 6.35; BL_{40} = 3.2	0.9 (ACTIVE ONLY)
TRANSMITTER UPCONVERTER ASSEMBLY	1/BLOCK	1:1*	0.743	0.6
FINAL UPCONVERTER & DRIVER	1/BEAM	1:1*	2.53	1.8
POWER AMPLIFIERS	1/BEAM	1:2	VARIES WITH DATA RATE ON EACH BEAM	
OUTPUT CIRCUITRY	1/BEAM	NONE	1.7	-
TRANSMIT ANTENNA	1	NONE	VARIES WITH NO. OF BEAMS	-

*REDUNDANT WITHIN A SINGLE PACKAGE
REDUNDANT COMPONENTS ARE NOT POWERED; 10% CHANNELS ADDED TO ACTIVE CHANNELS
BL_n = BLOCKS OF CHANNELS OF BANDWIDTH n MHz: 10 CHANNELS MAX. AT 10 MHz BANDWIDTH
5 CHANNELS MAX. AT 40 MHz BANDWIDTH

traffic rates of 500 to 20,000 Megabits/Second (Mbps) are investigated. Traffic is distributed in accordance with the geographical distribution of the population. Population, and hence, traffic levels are defined by cells whose angular width corresponds to that of the beams of a multiple beam antenna. The aggregate population in each cell is comprised of the sum of the population contained in areas identified as Standard Metropolitan Statistical Areas (SMSAs) and from smaller units, generically identified as non-SMSAs.

Distribution of the peak traffic is shown in Figures 4.1-2 to 4.1-8 and in Table 4.1-2 for a busy hour composite traffic load of 5 Gbps and antennas having 13, 19, 32, 46, 68, 100 and 178 beams. In the figures, each cell contains a beam number and the data rate in Mbps assigned to that cell on the basis of a total busy hour rate of 5 Gbps. Based on the assumption that the data rate is proportional to population, the data rate generated in any beam, say the ith beam, is given by:

$$C_{Bi} = \frac{\text{(POPULATION IN THE ith BEAM)}}{\text{TOTAL POPULATION}} \times \text{BUSY HOUR RATE}$$

Because the population is not distributed over the CONUS in a uniform or otherwise easily described way, the data rate per beam, as the number of beams is varied, cannot be calculated as the reciprocal of the number of beams. Varying the peak data rate with a constant beam configuration, however, does permit linear scaling because the geometric disposition of beams and hence population centers, does not shift.

With a small number of beams, large population centers in the Northeast dominate the system. In fact if the available bandwidth for CPS is limited to 1500 MHz, the systems using a small number of beams are not viable because nearly all the bandwidth is required in adjacent beams and frequency reuse cannot be effectively employed. Note that traffic cannot be expected to change in a linear manner with the number of beams, due to the rearrangement of geographical coverage when the number of beams changes. However, the traffic in each beam does decline as the number of beams increases except for the 13 and 19 beam cases where substantial redistribution of traffic occurs.

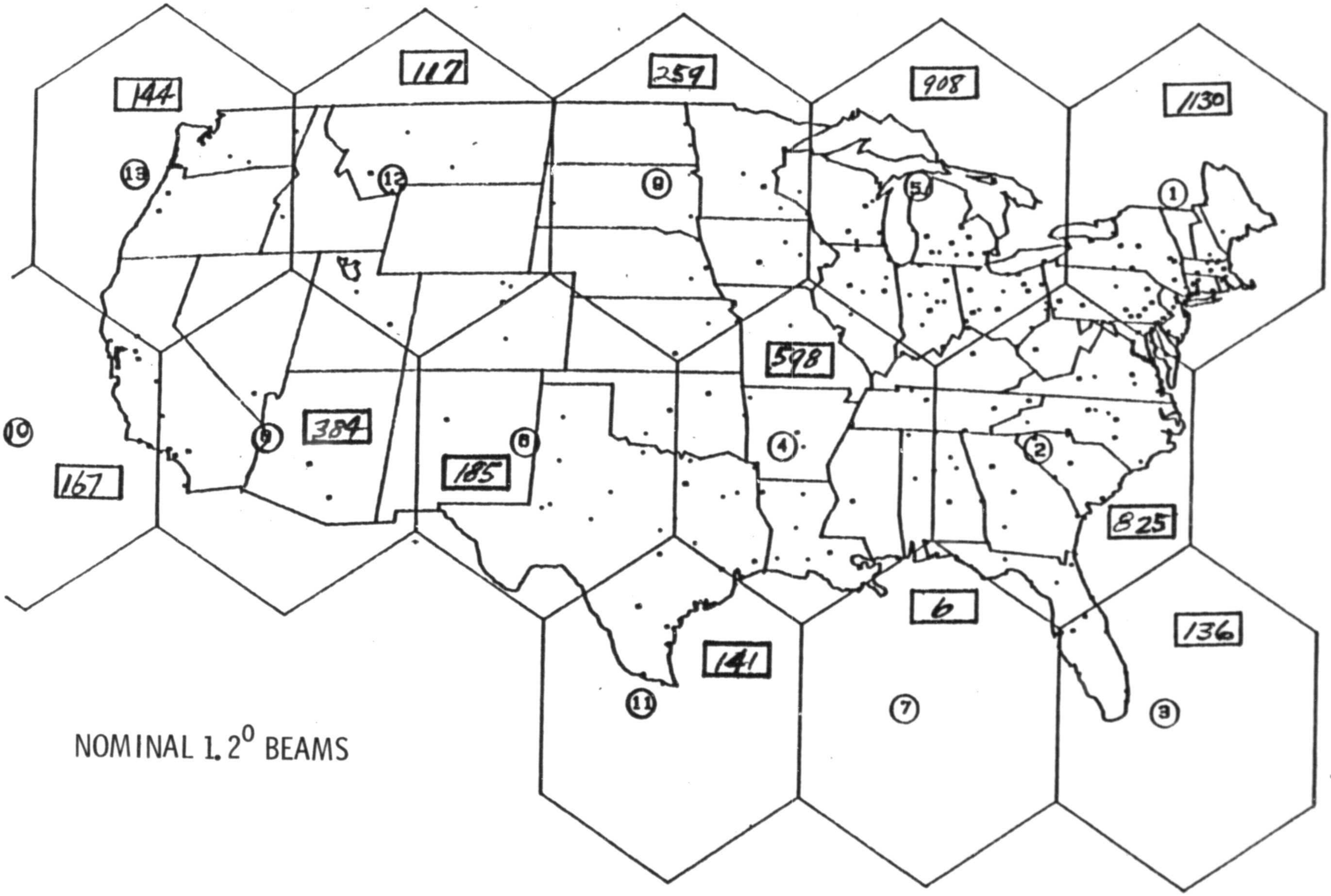


Figure 4.1-2. Geographic Distribution of Aggregate CPS Busy Hour Traffic MBPS: 5 Gbps Total Traffic and 13 Beams

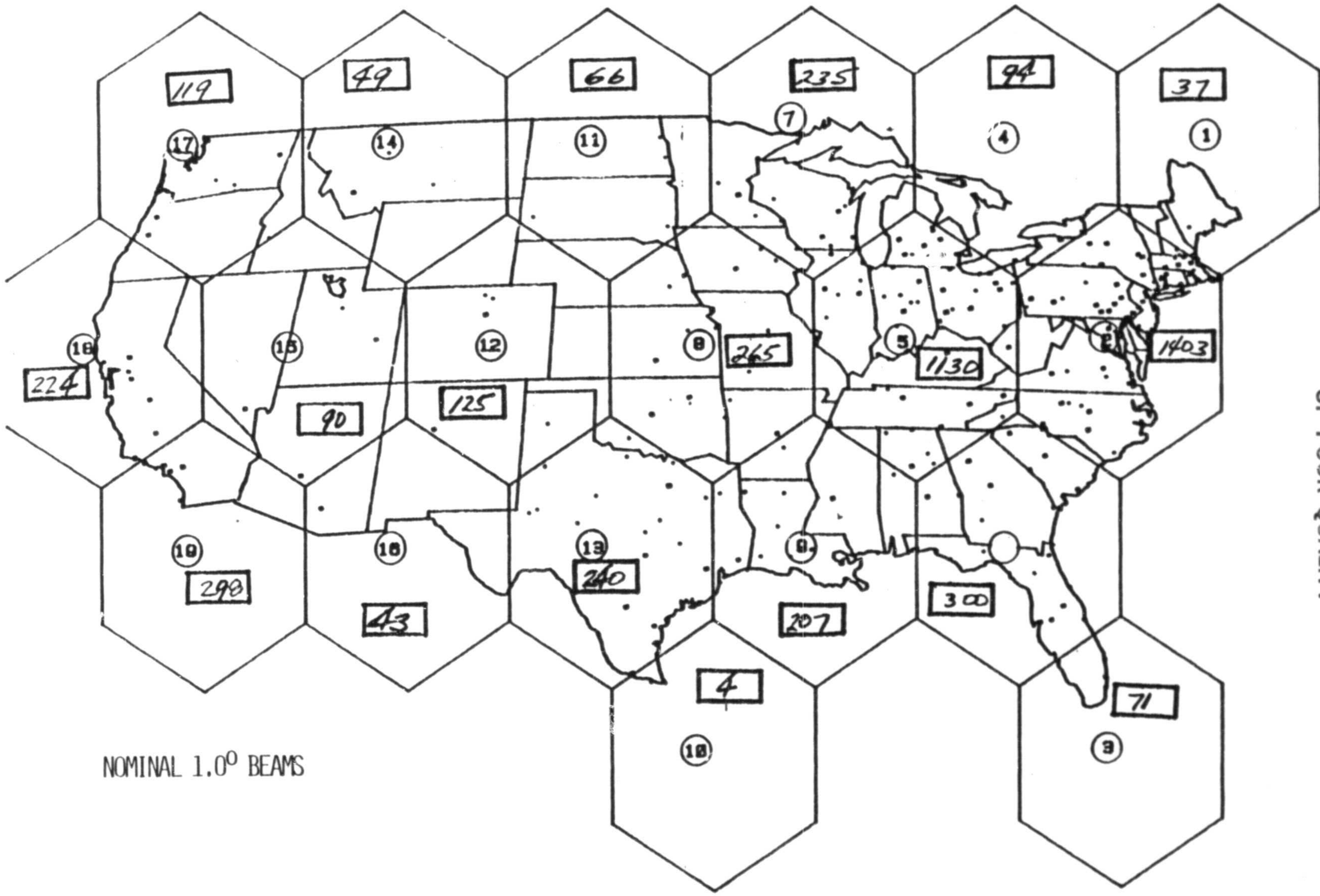
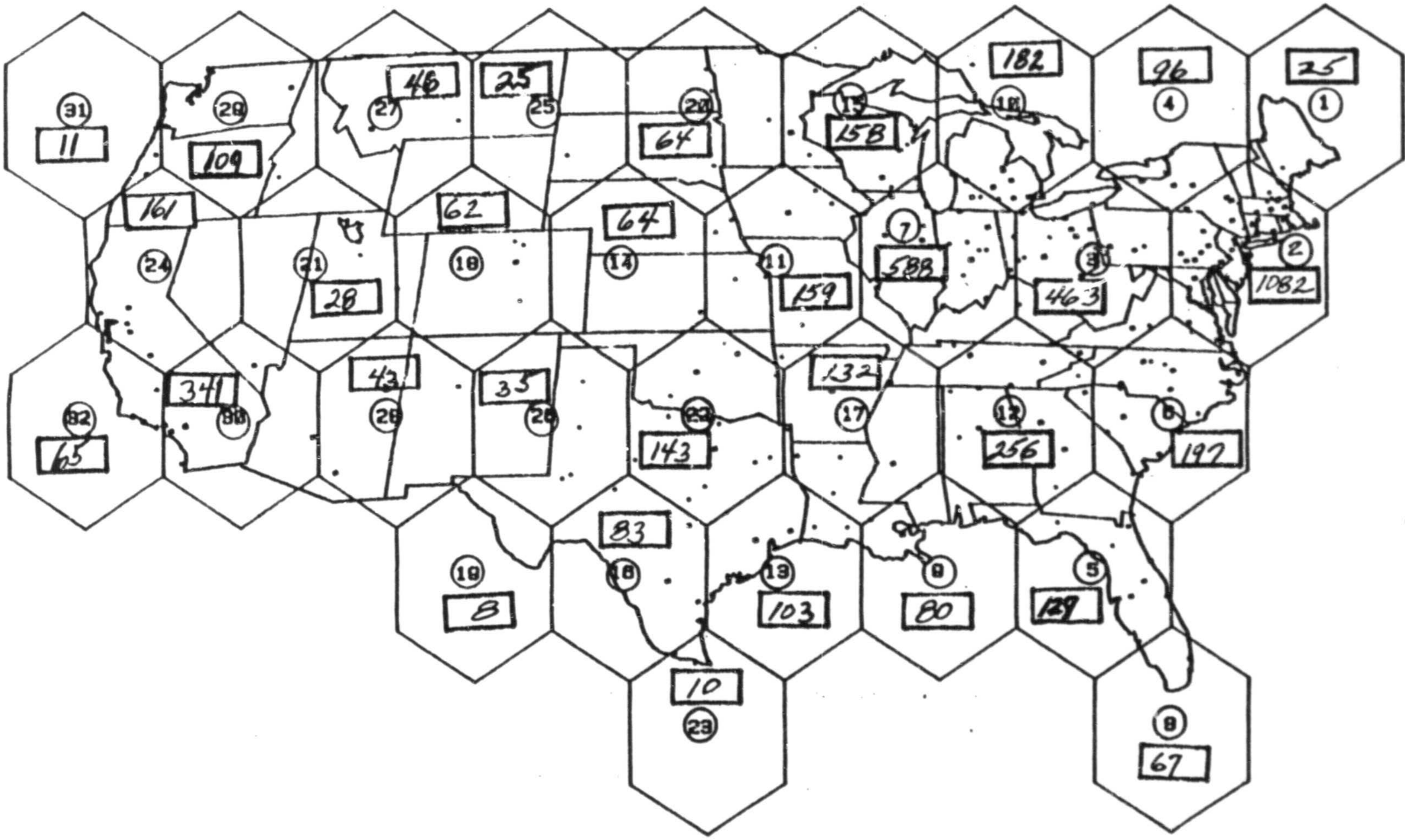


Figure 4.1-3. Geographic Distribution of Aggregate CPS Busy Hour Traffic MBPS: 5 Gbps Total Traffic and 19 Beams



NOMINAL 0.8^{0} BEAMS

Figure 4.1-4. Geographic Distribution of Aggregate CPS Busy Hour Traffic MBPS: 5 Gbps Total Traffic and 32 Beams

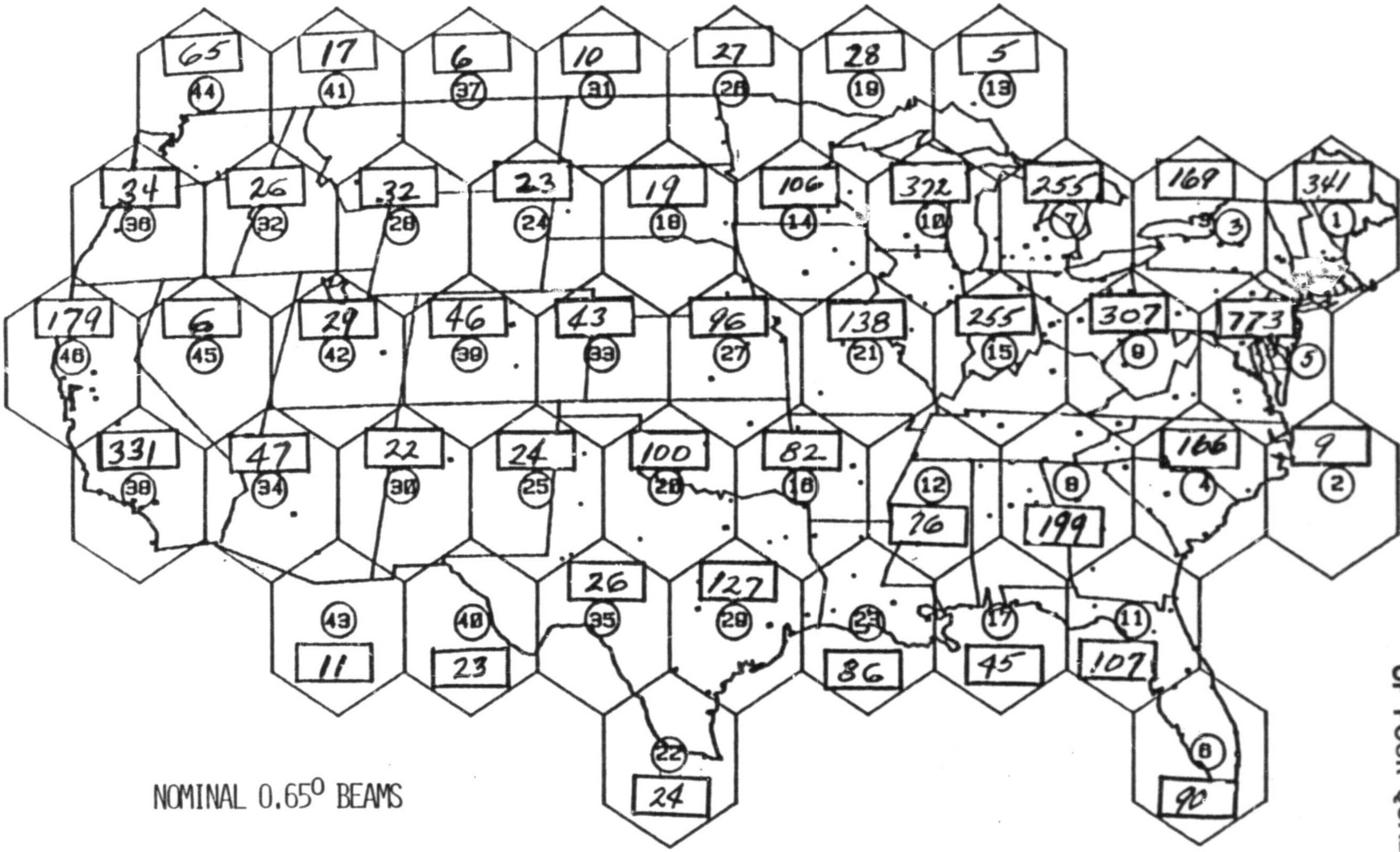


Figure 4.1-5. Geographic Distribution of Aggregate CPS Busy Hour Traffic MBPS: 5 Gbps Total Traffic and 46 Beams

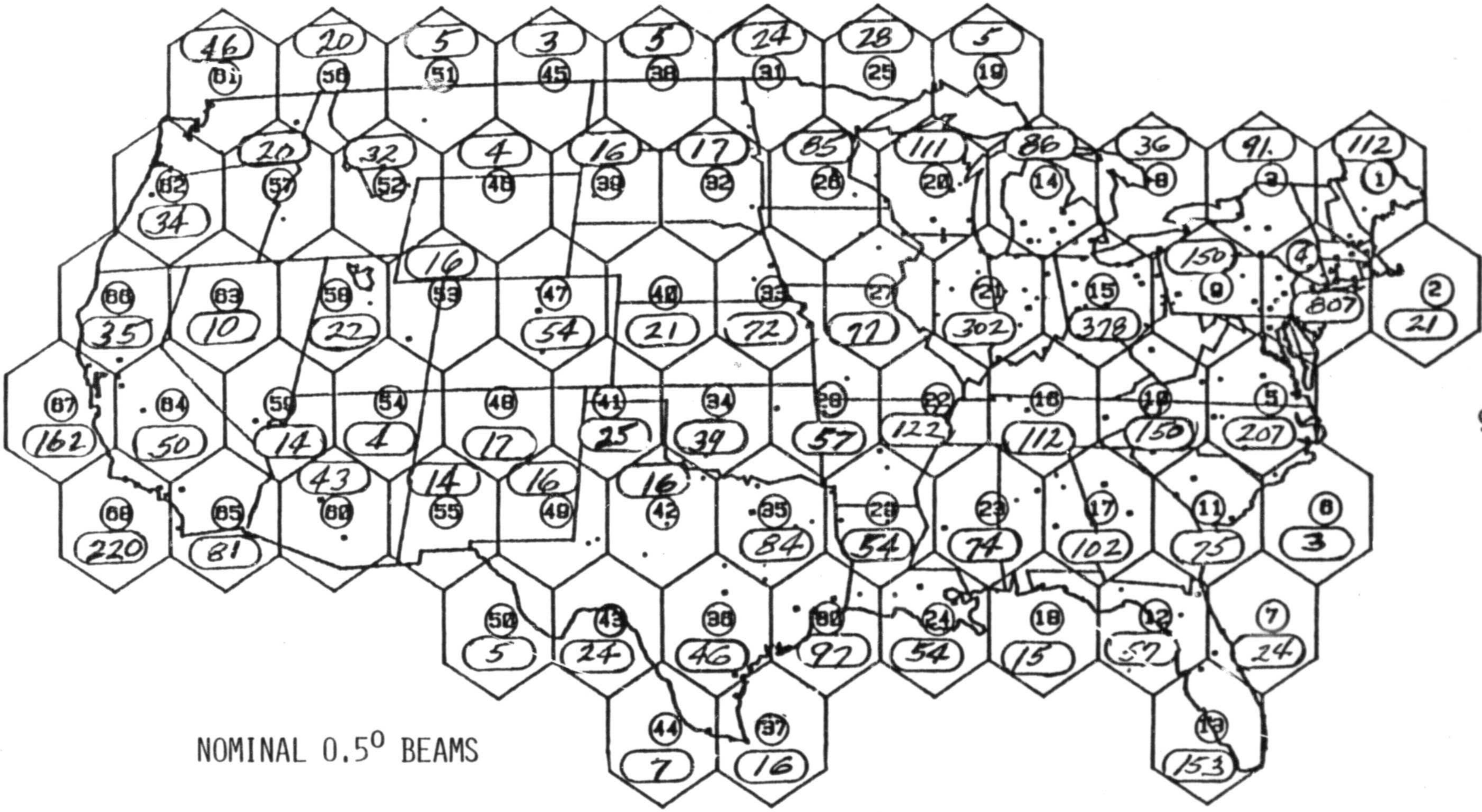


Figure 4.1-6. Geographic Distribution of Aggregate CPS Busy Hour Traffic MBPS: 5 Gbps Total Traffic and 68 Beams

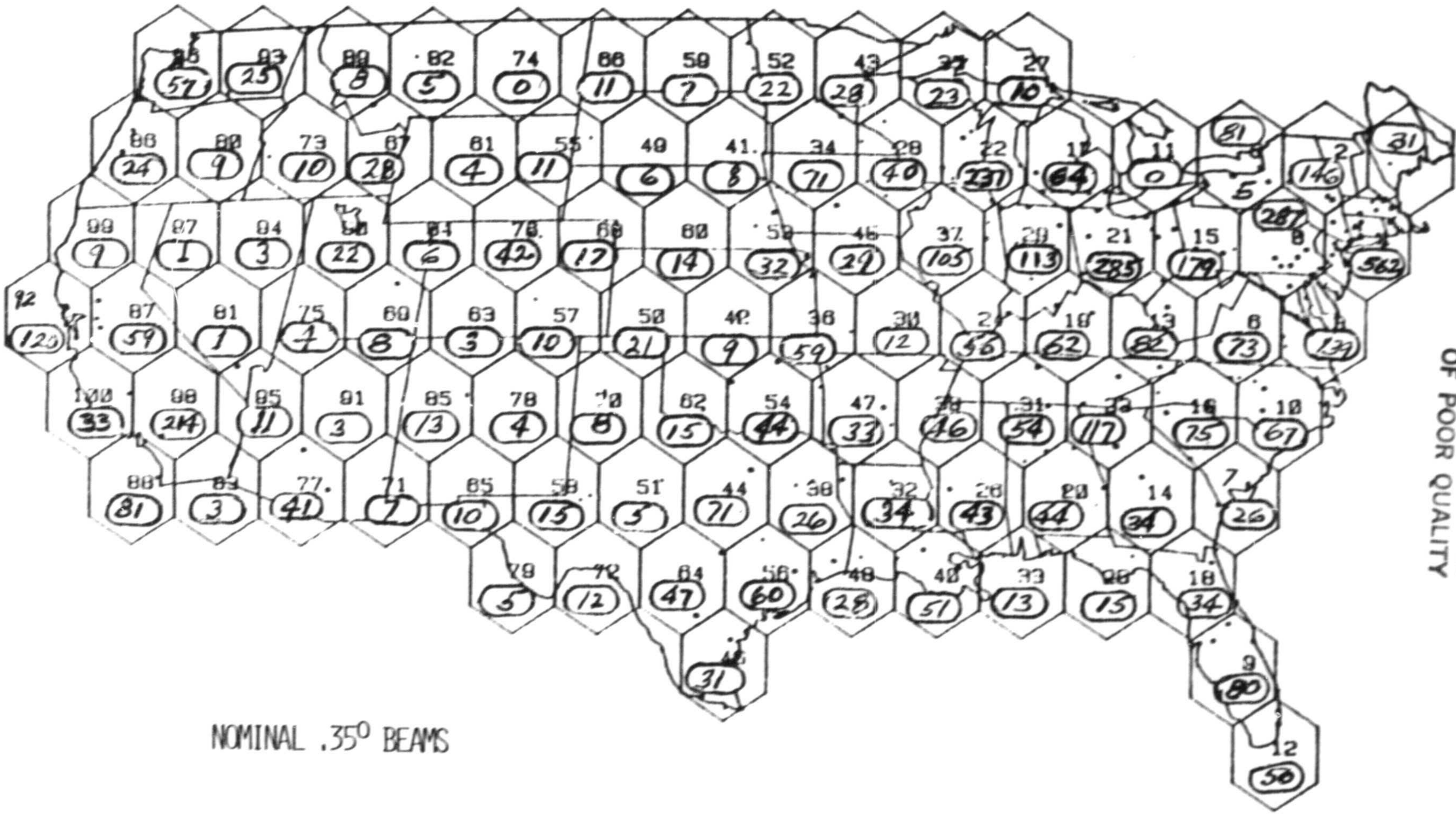
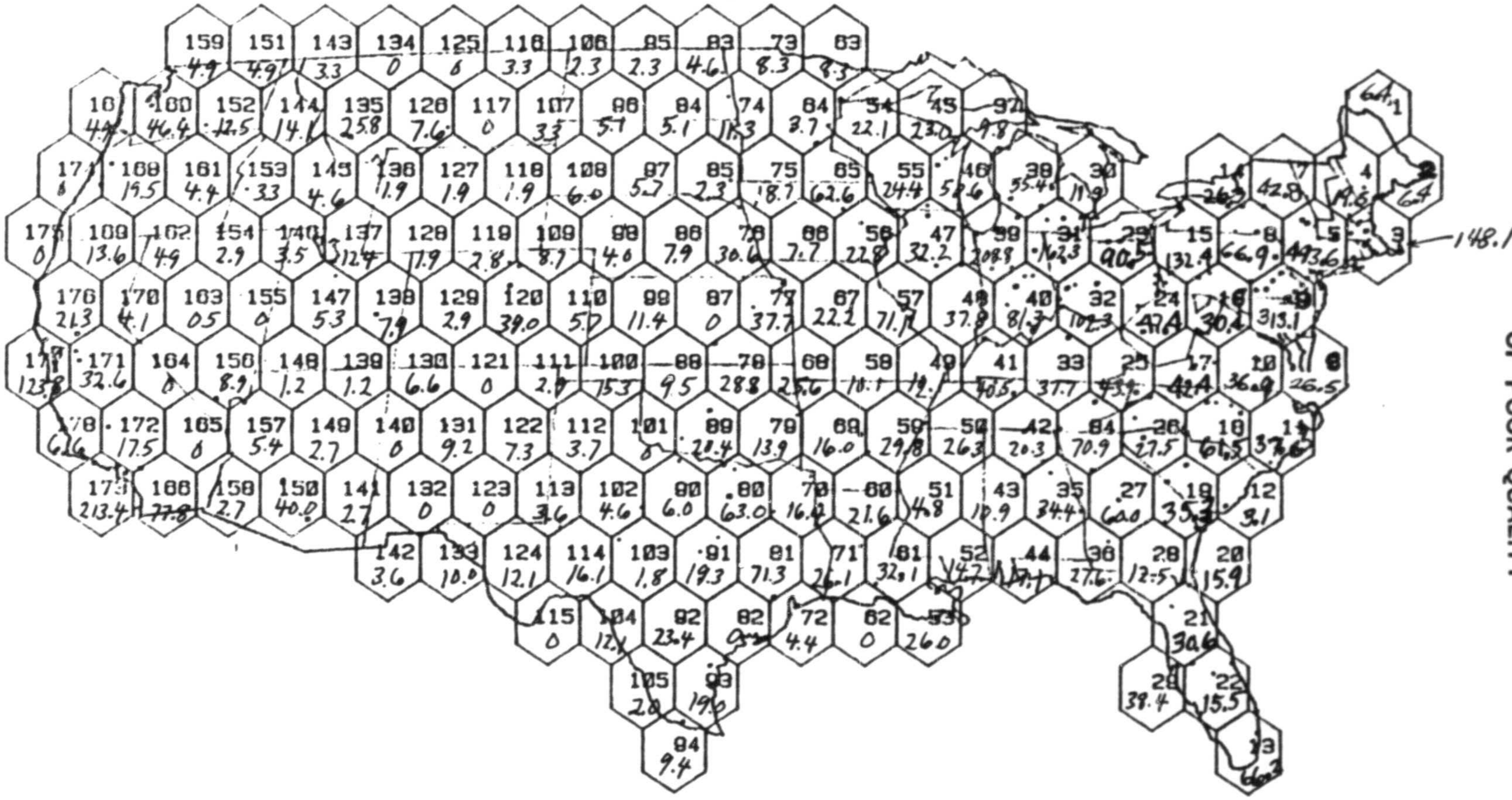


Figure 4.1-7. Geographic Distribution of Aggregate CPS Busy Hour Traffic MBPS: 5 Gbps Total Rate and 100 Beams



NOMINAL 0.3° BEAMS

Figure 4.1-8. Geographic Distribution of Aggregate CPS Busy Hour Traffic MBPS: 5 Gbps Total Rates and 178 Beams

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Table 4.1-2. Distribution of Traffic
By Beam Number, 178 Beams and Aggregate Rate of 5 Gbps

Beam Number	Traffic	Number	Beam Traffic	Number	Beam Traffic
1	6.4	44	17.1	89	20.4
2	6.4	45	23.0	90	6.0
3	148.1	46	50.6	91	19.3
4	19.6	47	32.2	92	23.4
5	493.6	48	37.8	93	19.0
6	26.5	49	10.1	94	9.4
7	42.8	50	26.3	95	2.3
8	66.9	51	4.8	96	5.1
9	313.1	52	14.7	97	5.7
10	36.9	53	26.0	98	4.0
11	37.6	54	22.1	99	11.4
12	3.1	55	24.4	100	15.3
13	66.2	56	22.8	101	0
14	26.3	57	71.1	102	4.6
15	132.4	58	10.1	103	1.8
16	30.4	59	29.8	104	12.1
17	42.4	60	21.6	105	2.0
18	61.5	61	32.1	106	2.3
19	35.3	62	0	107	3.3
20	15.9	63	8.3	108	6.0
21	30.6	64	3.7	109	8.7
22	15.5	65	62.6	110	5.7
23	90.5	66	7.7	111	2.9
24	47.4	67	22.2	112	3.7
25	43.9	68	25.6	113	3.6
26	27.5	69	16.0	114	16.1
27	60.0	70	16.4	115	0
28	12.5	71	26.1	116	3.3
29	38.4	72	4.4	117	0
30	11.9	73	8.3	118	1.9
31	162.3	74	11.3	119	2.8
32	102.3	75	18.7	120	39.0
33	37.7	76	30.6	121	0
34	70.9	77	37.7	122	7.3
35	34.4	78	28.8	123	0
36	27.6	79	13.9	124	12.1
37	9.8	80	63.0	125	0
38	55.4	81	71.3	126	7.6
39	208.8	82	0	127	1.9
40	81.3	83	4.6	128	1.9
41	40.5	84	5.1	129	2.9
42	20.3	85	2.3	130	6.6
43	10.9	86	7.9	131	9.2
44	17.1	87	0	132	0

TRAFFIC PER BEAM IS IN Mbps

Table 4.1-2. Distribution of Traffic
By Beam Number, 178 Beams and Aggregate Rate of 5 Gbps (Cont.)

Beam Number	Traffic	Number	Beam Traffic	Number	Beam Traffic
133	10.0	150	40.0	167	4.9
134	0	151	4.9	168	19.5
135	25.8	152	12.5	169	13.6
136	1.9	153	3.3	170	4.1
137	12.4	154	2.9	171	32.6
138	7.9	155	0	172	17.5
139	1.2	156	8.9	173	213.4
140	0	157	5.4	174	0
141	2.7	158	2.7	175	0
142	3.6	159	4.9	176	21.3
143	3.3	160	46.4	177	123.8
144	14.1	161	4.4	178	6.6
145	4.6	162	4.9		
146	3.5	163	0.5		
147	5.3	164	0		
148	1.2	165	0		
149	2.7	166			

TRAFFIC PER BEAM IS IN Mbps

As the number of beams increases, the illumination of the CONUS improves dramatically, leading to a better matching of the downlink flux density to the overall land mass and to the required traffic rates in the various SMSAs, resulting in a more efficient satellite.

For the 100 beam case, there are two beams in which no significant amount traffic is generated and for the 178 beam case there are 16 beams without significant traffic. Therefore, increasing the number of beams leads to a more optimum utilization of the satellite resources of G/T and EIRP. Note also, that small numbers of beams (and small apertures) are non-optimum simply because much of the illuminated area has either limited or no requirements for traffic. Since the distributions are shown for 5 Gbps distributed in accordance with population density, they may be easily adjusted to other aggregate rates simply by scaling according to the aggregate rate. Two approaches to the utilization of the traffic models are described below. One is based on postulated types of data users and the second is based upon the analysis of the traffic plan.

Calculated Weight For 30 GHz and 20 GHz Antenna Assemblies

Separate receiving and transmitting antenna assemblies are used in this study because the receiver and transmitter coverage areas must be matched, beam for beam. Separate antennas provides the most realistic way of accomplishing this objective.

Analyses of receiver and transmitter antenna weight are based on previous design exercises and assume the use of similar materials whose weight can be based on volumetric or area concepts. The antenna designs are each conceptually viewed as being comprised of a deployable reflector with offset feeds. Tables 4.1-3 and 4.1-4 contain the weight models for receive and transmit antennas respectively, based on using one feed horn per antenna beam. Equations are provided in each table for calculating the weight of similar antennas. Power is required by the receive antenna because it contains downconverters and low noise preamplifiers.

Very likely, multiple feeds per beam will be needed to achieve the required cochannel isolation between beams. So far, the investigation shows that the sidelobe levels can be controlled by energizing the feeds immediately surrounding the driven feed with a level that is one-tenth of the level in the central feed. This requires an array of fixed power dividers for transmit (or summing networks for receive). Hexagonal beam packing is assumed so that there will always be a primary feed as well as six secondary feeds for each desired spot beam location on the earth. Since each of the secondary feeds for one spot will also be primary feeds for other spots, the interconnection network will be complex. Additionally, it may also be necessary to provide some additional feeds to insure proper illuminations along the outside edges of the target area. As a minimum, for N feeds, there will be N weighted power dividers (Transmit) or N weighted summing networks (Receive). Because each feed is a primary feed for its own beam and is also a weighted feed for all adjacent primary beams a seven element (hexagonal packing) combiner is required at each feed to combine seven waveguide inputs.

Receiver Configuration and Channelization Plans

Each receive antenna beam incorporates a fully redundant receiver and downconverter, such as is shown in Figure 4.1-9. An image-enhanced, image-rejection balanced mixer design can be realized with state-of-the-art GaAs, beam lead, Schottky Diodes, embedded in a suspended quartz stripline

Table 4.1-3. Calculated Weight For 30 GHz Receive Antenna Assembly

No. of Beams	Reflector Diameter (in/Meters)	No. of Feed Horns	Reflector Area (ft^2)	Reflector Weight (Pounds)	Boom and Structure Weight (Pounds)	Hinge Weight (Pounds)	Feed Horn Weight (Pounds)	Platform Weight (Pounds)	Waveguide Weight (Pounds)	D/C & Preamp (Weight)	Antenna Weight (Pounds)
13	24.8/0.63	13	3.35	2.35	6.97	0.34	0.26	16.3	7.41	2.34	36.0
19	30/0.76	19	4.9	3.43	8.43	0.49	0.38	16.9	10.83	3.42	43.9
32	38.9/0.99	32	8.25	5.78	10.92	0.82	0.64	18.2	18.24	5.76	60.4
46	46.7/1.19	46	11.89	8.33	13.12	1.19	0.92	19.6	26.22	8.28	77.7
68	56.8/1.44	68	17.60	12.32	15.95	1.76	1.36	21.8	38.76	12.24	10.42
100	68.8/1.75	100	25.82	18.07	19.32	2.58	2.0	25.0	57.0	18.00	142.0
178	91.8/2.33	178	45.96	32.17	25.78	4.60	3.56	32.8	101.46	32.04	232.4

Nominal Frequency is 28 GHz

Reflector Weight = 0.7 A_R pounds, where A_R is the reflector area in square feet

Boom and Structure Weight = 3.37 D_R pounds, where D_R is the reflector diameter in feet

Power Hinge = 0.1 A_R Pounds

Feed Horn Weight = 0.02 N_F pounds where N_F is the number of feedhorns

Weight of first downconverter and preamp is 0.18 pounds. Each unit requires 0.75 watts regulated DC power.

Waveguide weight = 0.57 N_F pounds (10 ft lengths)

Antenna Weight, $W_A = N_F (0.1 + 0.02 + 0.57 + 0.18) + A_R (0.7 + 0.1) + 3.37 D_R + 15$ pounds

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W_A (28 GHz) = $0.87 N_F + 0.8 A_R + 3.37 D_R + 15$ pounds

Power = $0.75 N_F$

Table 4.1-4. Calculated Weight for 20 GHz Transmit Antenna Assembly

Beams	Reflector Diameter (In/Meters)	No. of Feed Horns	Reflector Area (ft^2)	Reflector Weight (Pounds)	Boom and Structure Weight (Pounds)	Power Hinge Weight (Pounds)	Feed Horn Weight (Pounds)	Feed Platform Weight (Pounds)	Waveguide Weight (Pounds)	Antenna Weight (Pounds)
13	38.6/0.98	13	8.13	5.69	10.84	0.81	0.39	16.3	11.18	45.2
19	46.7/1.19	19	11.88	8.31	13.12	1.19	.57	16.9	16.34	56.4
32	60.6/1.54	32	20.00	14.00	17.02	2.00	0.96	18.2	27.52	79.7
46	72.6/1.84	46	28.75	20.13	20.39	2.88	1.38	19.6	39.56	103.9
68	88.3/2.24	68	42.51	29.76	24.80	4.25	2.04	21.8	58.48	141.13
100	107.1/2.72	100	62.51	43.76	30.08	6.25	3.0	25.0	86.00	194.1
178	142.8/3.63	178	111.22	77.89	40.10	11.12	5.34	32.8	158.03	325.3

Nominal Frequency is 18 GHz

Reflector Weight = 0,7 A_R where A_R is the reflector area in square feet

Boom and structure weight = 3.37 D_R pounds, where D_R is the reflector diameter in feet

Power hinge weight = 0.1 A_R pounds

Feedhorn weight = 0.03 N_F where N_F is the number of feed horns

Feed platform weight = 15 + 0.1 N_F pounds   Waveguide weight = 0.86 N_F pounds (10 ft lengths)

Antenna Weight, $W_A = N_F (0.1 + 0.03 + 0.86) + A_R (0.7 + 0.1) + 3.37 D_R + 15$

W_A (18 GHz) = $0.99 N_F + 0.8 A_R + 3.37 D_R + 15$ pounds

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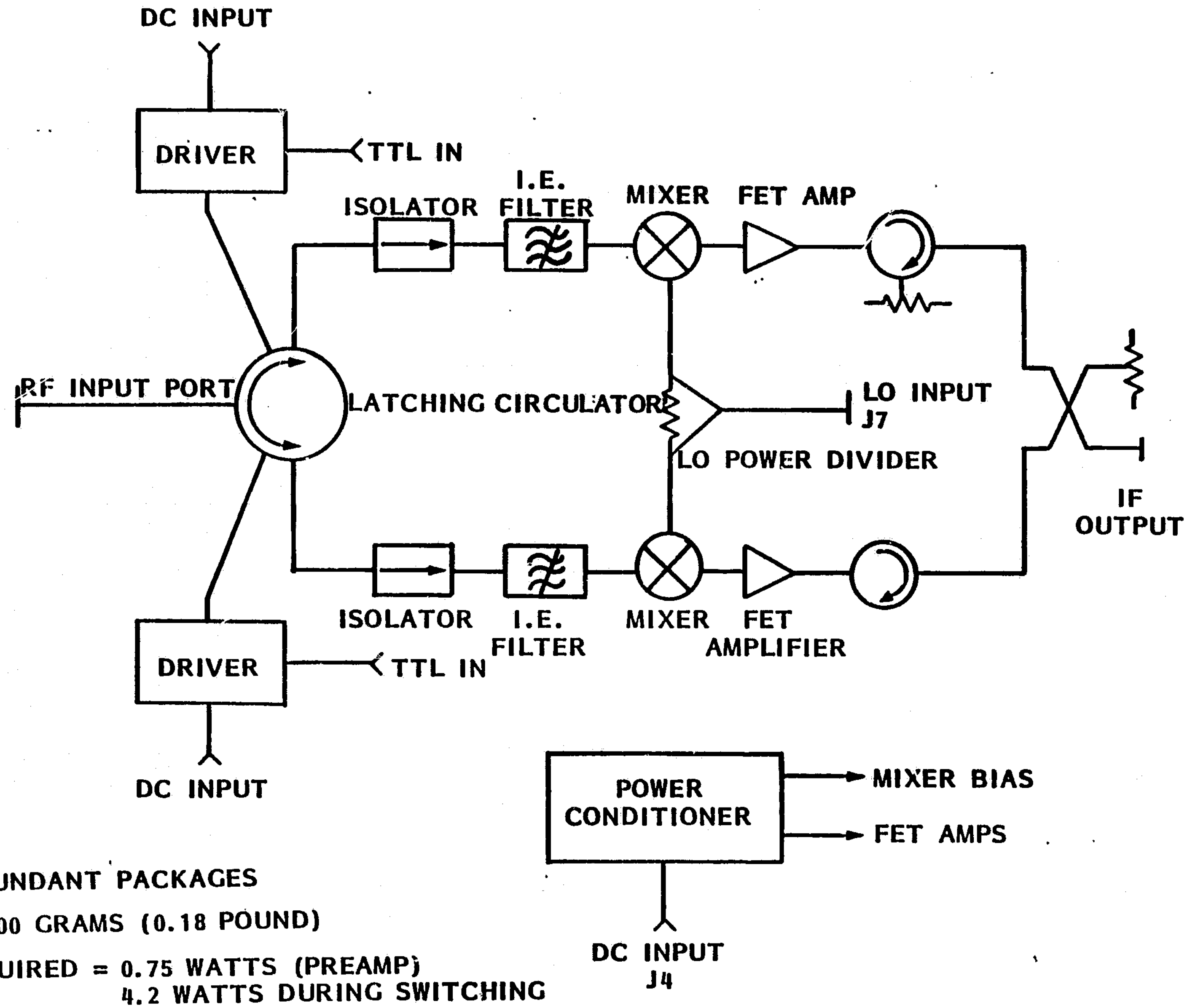

- FULLY REDUNDANT PACKAGES
- WEIGHT = 400 GRAMS (0.18 POUND)
- POWER REQUIRED = 0.75 WATTS (PREAMP)
  4.2 WATTS DURING SWITCHING

Figure 4.1-9. Receiver and First Downconverter Configuration

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circuit. A Ferrite latching circulator performs the function of an input redundancy switch. Output combining is accomplished passively and a nominal 20 dB gain IF preamplifier is required. Extensive analysis of requirements for Military EHF satellites and the results of 30 GHz transponder studies suggest that the fully redundant configuration in Figure 4.1-9 is a viable approach for a long-life satellite. If a single IF output is determined to be objectionable (it represents a single point failure) dual IF outputs can easily be provided with some penalty in weight for the additional coaxial cable.

One receiver and downconverter assembly with redundancy has a calculated weight of 0.68 pound, based upon an analysis and design of a similar unit designed to operate at 44 GHz. One redundant unit is required for each receive antenna beam, therefore the total weight and power is proportional to the number of beams.

Channelization Plans and Hardware Requirements

Two approaches to the development of a channelizing plan have been explored. The first approach is based upon market studies and a hypothesized distribution of data users and the second is based upon a traffic analysis. Examination of these two approaches is instructive because they lead to different channelizing strategies.

The SS-FDMA satellite payload channelization requirements are first developed from the hypothesized relative distribution of data types and characteristics generated as summarized in Table 4.1-5. For purposes of channelizing the FDMA payload, we assume that voice and video information services will be channelized in 10 MHz bands. Allowing for some roundoff, the capacity of the SS-FDMA satellite payload are allocated in the following manner:

1. 60% of the bandwidth in 10 MHz channels (15 Mbps capacity in each channel).

2. 40% of the bandwidth in 10 MHz channels (60 Mbps capacity in each channel).

On the basis of this rationale, the number of channels in the payload can be defined as a function of data rate and provision for 10% spares. While

Table 4.1-5. Relative Peak Capacity For User Classes and Traffic Services in the CPS, With Concentration and Diversity

USER CLASS	1990						2000					
	VOICE	VIDEO CONF.	VIDEO INFO SERVICES	DATA, MESSAGES	DATA, COMPUTER	TOTAL USER	VOICE	VIDEO CONF.	VIDEO INFO. SERVICES	DATA, MESSAGES	DATA, COMPUTER	TOTAL USER
BUSINESS	0.4161	5.6^{-2}*	6.51^{-2}	9.38^{-3}	0.1286	0.6752	0.4047	8.64^{-2}	5.25^{-2}	5.36^{-3}	0.1146	0.6636
GOVERNMENT	0.1211	2.4^{-3}	2.79^{-3}	3.65^{-2}	0.1655	0.1178	0.1178	4.05^{-3}	2.46^{-3}	1.52^{-3}	3.25^{-2}	0.1583
INSTITUTIONS	8.38^{-2}	2.16^{-2}	2.51^{-2}	1.82^{-3}	2.5^{-2}	0.1573	8.15^{-2}	4.32^{-2}	2.62^{-2}	1.04^{-3}	2.22^{-2}	0.17414
PRIVATE HOMES & CONDOMINIUMS	0	0	0	0	2^{-3}	2^{-3}	0	0	2.2^{-3}	0	1.8^{-3}	4.0^{-3}
TOTAL TRAFFIC SERVICE	0.621	8.0^{-2}	9.3^{-2}	1.39^{-2}	0.1921	1.0	0.604	0.1336	8.34^{-2}	7.9^{-3}	0.171	1.0

*THE NOTATION, 5.6^{-2}, IS DEFINED AS IDENTICAL TO 5.6×10^{-2}.

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reducing the number of spares will reduce the weight estimate, the capacity for growth and improved reliability will be restricted.

The basic channelization plan is given in Table 4.1-6. Data packing density was assumed to be 1 Bit/1.544 Hz (although 1 Bit/Hz appears feasible), including guard bands. Quaternary Phase Shift Keying (QPSK) with 1/2 bit offset or MSK is used. Figures 4.1-10 and 4.1-11 demonstrate a typical channelizing plan for the receiver and transmitter respectively. In this plan, 5 MHz is reserved for a common signalling channel. This produces a channelizing plan that is readily scalable to other data rates and number of teams. With a 1/4 frequency factor, four different L.O. frequencies are used in the second downconverters of the different beams. The third downconverter local oscillator and channelizing local oscillator frequencies are chosen to provide uniform 200 MHz IF outputs.

Bandwidth of the first and second downconverters in Figure 4.1-10 is the assumed system bandwidth of 1500 MHz. After this second downconversion, filtering is used to separate the signals into five 40 MHz channels and two banks of ten 10 MHz channels. Observe that this functional description of the payload omits many details of the hardware which are explicitly accounted for in the weight and power budgets.

The channelizing units are comprised of power dividers, UHF double balanced mixers and output bandpass filters. Surface Acoustic Wave (SAW) filters are appropriate for the third downconverter post-mixer filter and for all filters in the channelizing units. Since there are large quantities of channelizing units on each spacecraft, they represent a unique engineering and manufacturing challenge, specifically in the areas of weight reduction and miniaturization, as discussed later. Since the local oscillators for the 40 MHz and 10 MHz channelizing units are incremented in 40 MHz and 10 MHz segments respectively, comb generators are a light-weight and low-power solution for this application and will be shared between the receiver and the transmitter channelizing units.

Figure 4.1-11 shows the transmitter channelizing plan to be a mirror-image of the receiver plan. Upconversion to the final output frequency also utilizes the receiver local oscillators, except for a 500 MHz frequency offset. As in

Table 4.1-6. SS-FDMA Channelization Plan Based on Data Type Distribution (Two Levels of Bandwidth Quantization)

RATE (MBITS/SEC)	NUMBER OF CHANNELS, M′				TOTAL CHANNELS M
	NARROWBAND		WIDEBAND		
	10 MHZ	10 MHZ SPARES	40 MHZ	40 MHZ SPARES	
500	30	3	5	1	39
1000	60	6	10	1	77
2000	120	12	20	2	154
5000	300	30	50	5	385
10,000	600	60	100	10	770
15,000	900	90	150	15	1155
20,000	1200	120	200	20	1540
40,000	2400	240	400	40	3080

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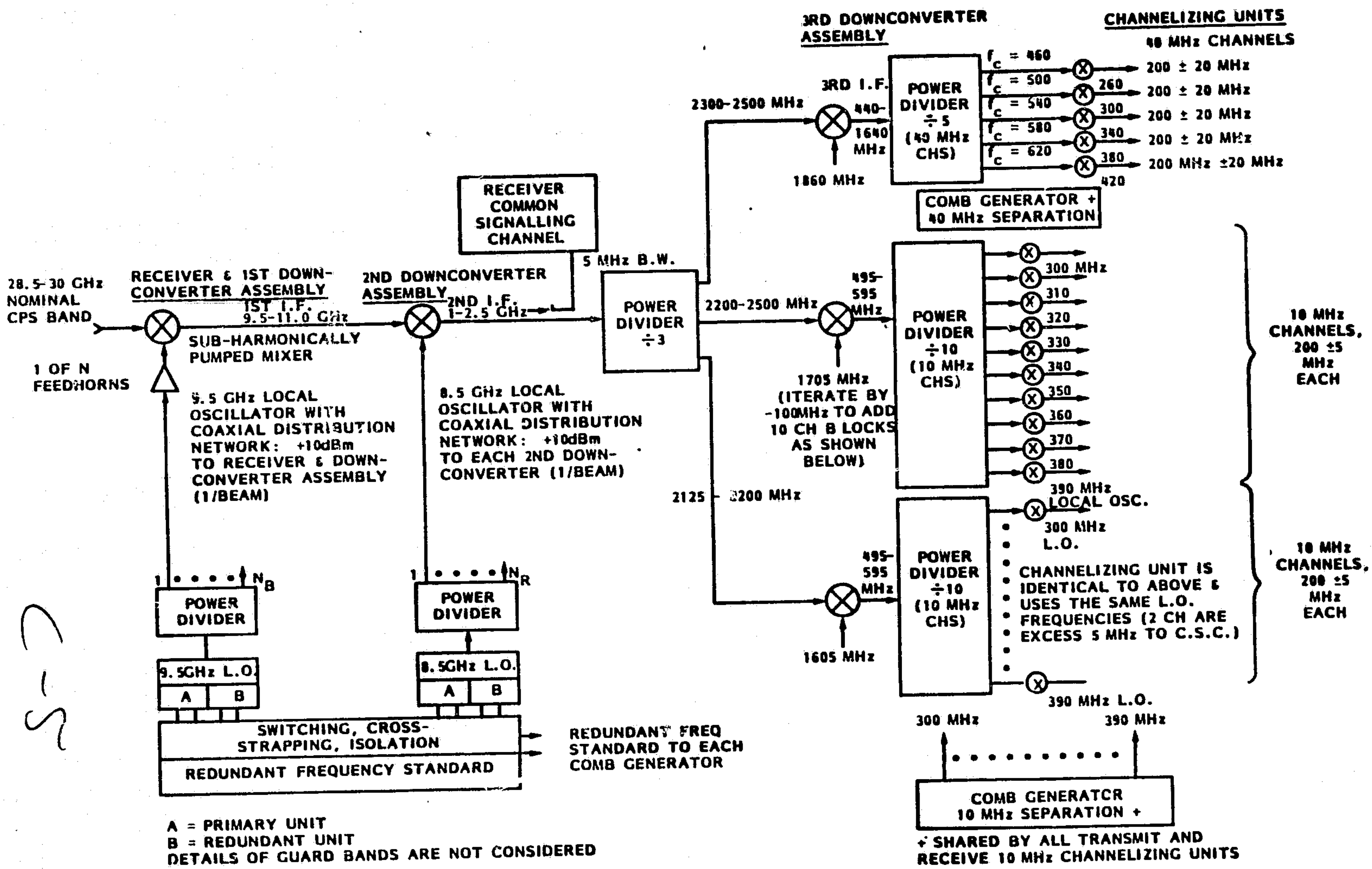

Figure 4.1-10. Functional Description of a SS-FDMA Receiver Channelization Plan

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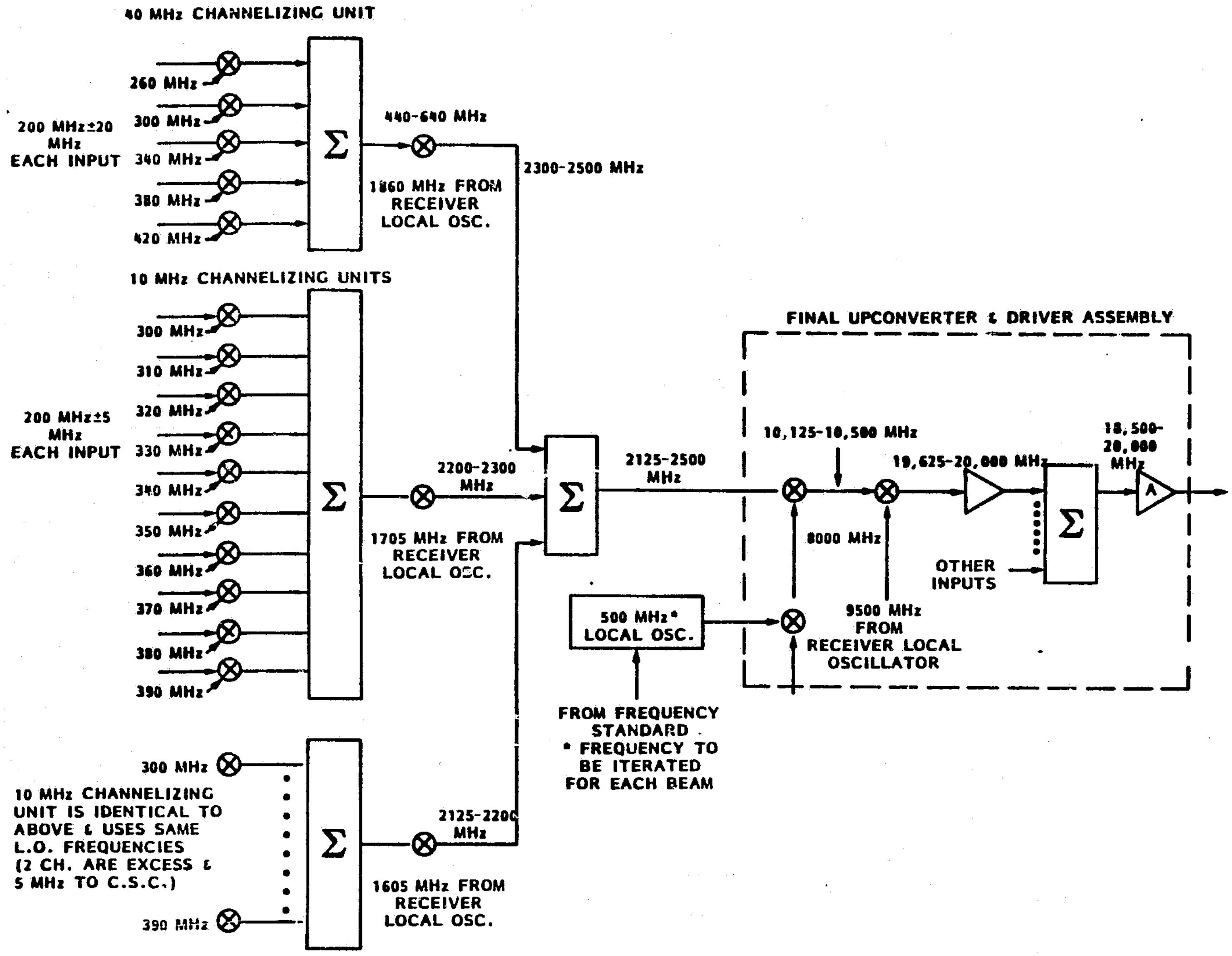

CHANNELIZING UNIT LOCAL OSCILLATORS ARE FROM POWER DIVIDER OUTPUTS OF THE RECEIVER CHANNELIZING LOCAL OSCILLATORS. FREQUENCIES ARE IDENTICAL.

Figure 4.1-11. Functional Description of a SS-FDMA Transmitter Channelization Plan

the receiver, 5 MHz has been allocated to the Common Signalling Channel (CSC) and two 10 MHz channels are assigned as spares to account for the non-integer number of channels.

The plan described in this subsection does not utilize the spectrum nearly as efficiently as one that allows for more small users. The case of large numbers of small users is explored and analyzed in detail in the following.

Detailed review of traffic flow within the CPS system shows that low data rates only are required between many of the beams. The spectrum efficiency of the CPS network is a function of the number of bandwidth quantization levels and frequency utilization improves with the use of several channel bandwidths. In the previous paragraphs, the channelizing structure is based upon two levels of quantization, 10 MHz and 40 MHz. The traffic analysis shows that three levels of quantization leads to a large increase in spectrum efficiency while four levels of quantization provides only small additional improvement. Consequently, we adopt three levels of bandwidth quantization and examine the receive architecture with quantization into 40 Mbps channels, 6-T1 channels and single T1 channels.

The traffic analysis leads to the channelization plan of Table 4.1-7. A number of the channels have been preassigned to specific downlink beams and are therefore removed from the switch matrix. However, the prepondence of T1 channels means that the total channelization is higher and that many more channelizing units are required when compared to the plan for two quantization levels. As a result, the satellite burden can be expected to be exorbitant if conventional implementation approaches are taken.

Since the number of channelizing units is large, conventional hybrid circuitry will not produce a sufficiently light weight design that conserves D.C. power. An implementation approach that is capable of achieving this goal involves the use of Monolithic Microwave Integrated Circuits (MMICs). Piece part monolithic clips would be integrated to form a single fully monolithic module. Other components include Surface Acoustic Wave (SAW) filter chips and monolithic amplifier chips when needed.

Table 4.1-7. SS-FDMA Channelizing Plan Based on Traffic Analysis

RATE (Mbps)	40 Mbps CHANNELS			6.176 Mbps (4 T-1 CH)			1.544 Mbps CHANNELS			TOTAL PRE-ASSIGNED	TOTAL SWITCHED	TOTAL SPARES
	PRE-ASSIGN	SWITCH	SPARES	PRE-ASSIGN	SWITCH	SPARES	PRE-ASSIGN	SWITCH	SPARES			
500	0	0	0	0	0	0	2138	46	218	2138	46	218
1,000	0	0	0	16	8	3	2148	46	218	2164	54	221
2,000	0	0	0	86	20	11	2148	46	218	2234	66	229
5,000	12	4	2	324	60	38	2148	109	226	2484	173	266
10,000	55	24	8	719	97	82	1919	151	207	2693	272	297
15,000	98	47	14	1114	135	125	1691	194	189	2903	376	328
20,000	200	80	28	1114	135	125	1691	194	189	3005	409	342
40,000	500	240	74	1114	135	125	1691	194	189	3305	589	388

ALL SPARES ARE SWITCHED. FOR SS-FDMA UPLINK & DOWNLINK, THE NUMBER OF CHANNELIZING UNITS IS DOUBLED.

Significant progress is now being made by General Electric in an effort to develop monolithic transceivers for S-band radar systems on a development program for DARPA. Each monolithic element of the transceiver module contains the elements shown in Table 4.1-8. Projected weight for this module ranges from 2.1 to 10 grams for the MMIC chip. An examination of the relative complexity of the S-band transceiver module is made in Table 4.1-9 and shows that it is comparable to the CPS channelizing units which need to be implemented in the S-band region and lower. Taking conservative estimates for weight and power gives the following requirements for CPS:

1. Channelizing Unit Weight: 0.094 Pounds (Potential reduction to 0.03 lbs)
2. Channelizing Unit Power: 270 mW

Channelizing unit requirements are summarized in Table 4.1-10 for the two levels of bandwidth quantization and in Table 4.1-11 for three levels of quantization. Weight can be reduced even further by integrating the receive and the transmit channelizing units with a partitioned switch matrix.

Other weight and size reductions are necessary to accommodate the preassigned channelization structure. As a minimum, there would be at least 10 channelizing units integrated with the input power divider. This monolithic structure would weigh in the order of 25-30 grams, but, would require 10 output connectors to permit interconnection of each channel to the desired downlink beam for additional weight of about 300 grams, leading to a total weight of 330 grams or about 0.15 pounds.

For N preassigned channels (Npach) the total number of preassigned channel units is:

$$N_{pacu} = \frac{N_{pach}}{10}$$

Table 4.1-8. Accomplished and Projected Results For an S-Band MMIC Transceiver

Circuit Element	Requirement	Demonstrated*	Projected*
<u>Power Amplifier</u>	3-4 Stages		
Efficiency (L&S BAND)	30%	17-30	18-30
Peak Power (WATTS)	0.5W	0.5 to 0.66	0.5 - 0.63
Gain (dB)	5-25	6-22	3.9 - 32
D.C. Power (WATTS)	Low	2.5 - 5.9	2.1 - 3.8
<u>Low Noise Amplifier</u>	3-4 Stages		
Noise Figure (dB)	3.5	4.2 - 7.0	2.8 - 5.5
Gain (dB)	15-25	14-23	17-32
D.C. Power (WATTS)	Low	0.2(S)-0.3(L)	0.040-0.18
<u>Transmit/Receive Switch</u>	2 Switches		
Insertion Loss (dB)	Low	0.5-0.8	0.4-0.6
Isolation (dB)	High	16-30	22-23
D.C. Power (WATTS)	Low	0.003	0.0024
<u>Phase Shifter (4 B.T.)</u>	1 Phase Shifter		
Insertion Loss (dB/Bit)	Low	1.5-8	0.7-6.0
Bandwidth (MHz)	10%	10%	10%
DC Power	Few mW	2.4 mW	2-6.4 mW
<u>System Constraints</u>			
Weight (grams)	1-10		2.1 to 10
DC Power	Low		245 MW
Reliability & Life	5 years		0.112inx0.112 in
Module Chip Size		0.172inx0.172in	0.28inx0.51 in 0.76inx0.72 in x0.125 in

*RANGES OF ALL VENDORS COMBINED
(S) = S-BAND, (L) = L-BAND

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Table 4.1-9. Relative Complexity of S-Band MMIC Transceiver and CPS Modules

S-BAND TRANSCEIVER	EQUIVALENT COMPLEXITY, CPS MODULE
POWER AMPLIFIER, 3-4 STAGES	INPUT I.F. AMPLIFIER, 3 STAGES
LOW NOISE AMPLIFIER	OUTPUT I.F. AMPLIFIER, 2 STAGES
2 T/R SWITCHES	2 SAW FILTERS
1, 4-BIT PHASE SHIFTER	1 MIXER + L.O. AMPLIFIER (1 STAGE)
CHIP WEIGHT: 2-10 GRAMS	10 GRAMS + CASE 1.5 OZ. = 0.094 LBS.
POWER: DRIVEN BY POWER AMPLIFIER	USE LNA AS A GUIDE TO AMPLIFIER POWER REQUIREMENTS: 180 mw/4 STAGES = 45 mw/STAGE. POWER REQUIRED IS 45 mw x 6 STAGES = 270 mw
CHIP SIZE: 0.112 IN. x 0.1/2 IN. TO 0.76 IN. x 0.72 IN. x 0.125 IN. (PROJECTIONS)	CASE SIZE = 1 IN. x 1 IN. x 0.25 IN.

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Table 4.1-10. Summary of SS-FDMA Channelizing Units Required - Two Levels of Bandwidth Quantization

	Number of channels, M						
	Narrowband		Wideband				
(Mbits/Sec)	10 MHz	10 MHz Spares	40 MHz	40 MHz Spares	Total Channel M	Weight (Pounds)	Power (Watts)
500	30	3	5	1	39	3.7	9.5
1000	60	6	10	1	77	7.2	18.9
2000	120	12	20	2	154	14.5	37.8
5000	300	30	50	5	385	36.2	94.5
10000	600	60	100	10	770	72.4	189.0
15000	900	90	150	15	1155	108.6	283.5
20000	1200	120	200	20	1540	144.8	378.0
40000	2400	240	400	40	3080	289.5	756.0

Weight: 0.094 pounds/channelizing unit; Power = 270 mw/Active Unit

For SS-FDMA Uplink and downlink, the weight and power is doubled

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Table 4.1-11. Summary of SS-FDMA Channelizing Units Required - Three Levels of Bandwidth Quantization

RATE Mbps	PRE-ASSIGNED & SWITCHED	SPARES (NOT ACTIVIATED UNTIL REQUIRED)	TOTAL CHANNELIZING	WEIGHT POUNDS	POWER WATTS
500	2184	218	2402	225.8	589.7
1000	2218	221	2439	229.3	598.9
2000	2300	229	2529	237.7	621.0
5000	2657	266	2923	274.8	717.4
10,000	2965	297	3262	306.6	800.6
15,000	3279	328	3607	339.1	885.3
20,000	3414	342	3756	353.1	921.8
40,000	3874	388	3693	347.1	1046.0

o WEIGHT: 0.094 Pounds/Channelizing Unit; Power = 270mW/Active Unit

o For SS-FDMA Uplink & Downlink the weight & Power is doubled

1. 40 Mbps Channels: 26 MHz
2. 6.196 Mbps Channels: 4.0 MHz
3. 1.544 Mbps Channels: 1.0 MHz

The weight of each unit is 0.15 pounds and it requires 2.7 watts. Additional coax is 3 ft/unit @ 0.1 pounds/foot. The total weight of the preassigned channel unit is,

$$W_{pacu} = 0.15 \frac{N_{pach}}{10} + 0.3 \frac{N_{pach}}{10}$$

$$W_{pacu} = 0.45\ N_{pach} \text{ pounds}$$

and the power required is

$$P_{pacu} = 2.7 \frac{N_{pach}}{10} = 0.27 \ N_{pach} \text{ watts}$$

As discussed previously, the required channel bandwidth is 0.65 x Data Rate for 1/2 Bit offset, QPSK modulation. Channel bandwidth allocations for three levels of quantization are therefore, as follows:

When two-level quantization was examined, the 40 MHz and 10 MHz channels were assigned 60 Mbps and 15 Mbps of data, respectively. Bandwidth occupancy is approximately 1 MHz per T1 channel and the expected frequency reuse interval of 375-400 MHz will allow exactly that many simultaneous T1 users. Also, the bandwidth allocation to the CPS is not yet established and when this occurs, some of the system approaches and data loadings may become impractical. Consequently, the approach to defining the satellite loading on the basis of:

1. 40 Mbps Channels: 26 MHz
2. 6.196 Mbps Channels: 4.0 MHz
3. 1.544 Mbps Channels: 1.0 MHz

one frequency reuse will be abandoned and loading will be established on the basis of the aggregate data rate, with example loadings shown for a well defined beam and data rates, an artifice that readily allows for scaling the payload in accordance with the traffic loading.

Figure 4.1-12 demonstrates the SS-FDMA payload structure for the New York beam with three quantization levels in bandwidth, when the aggregate data rate is 773 Mbps, corresponding to a 46 beam system. At 773 Mbps, 128 receive and 128 transmit channelizing units are required to support the New York beams alone.

Uplink-downlink connectivity is established through the IF switch matrix for all switched channels. Preassigned channels bypass the switch matrix and are hardwired. Hardwiring will be accomplished by connecting the IF output of the receive channelizing units to summing networks, one summing network assigned to each beam. The output of the summing network represents a reserved frequency allocation for preassignment to that downlink.

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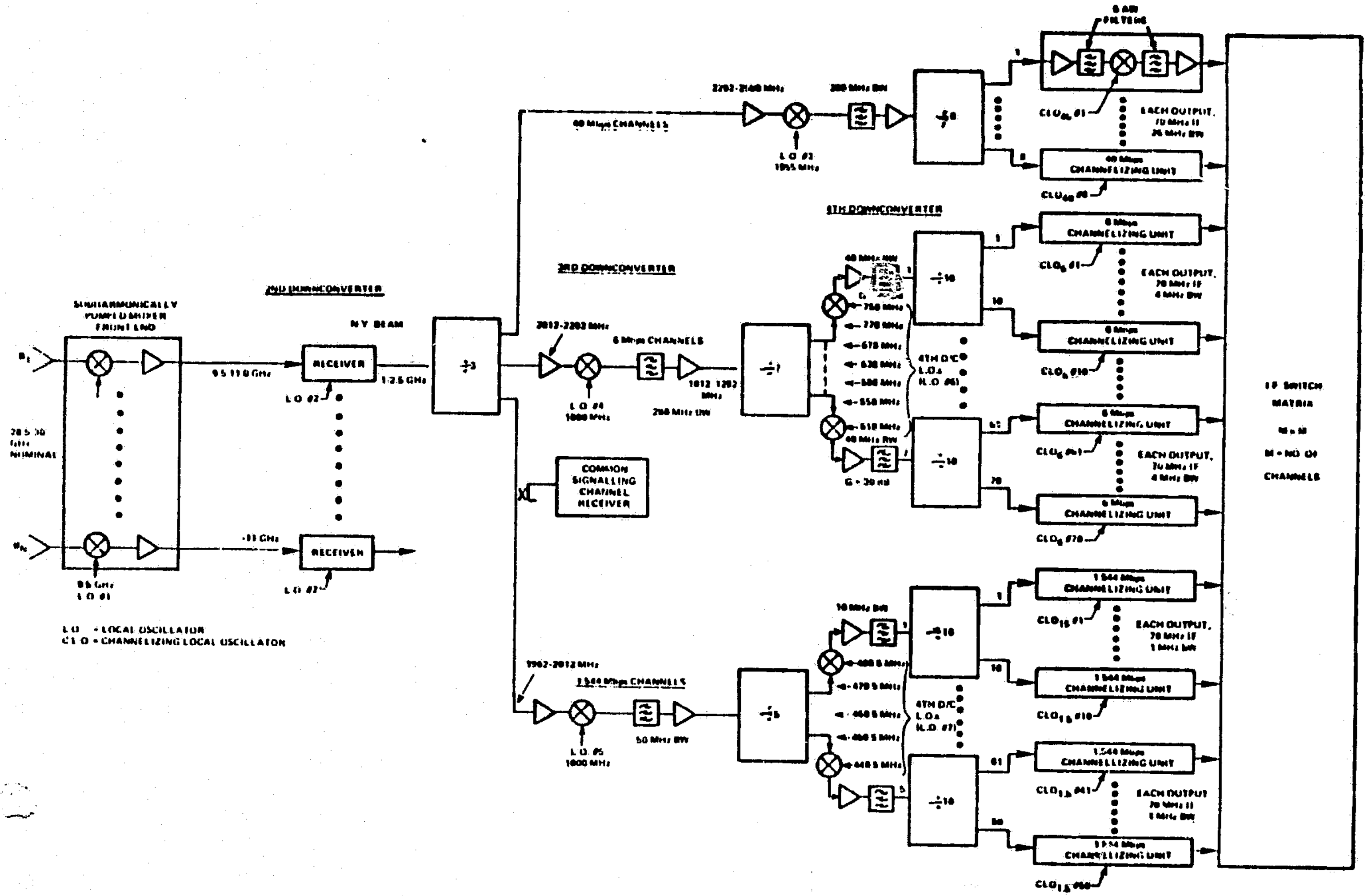

Figure 4.1-12. SS-FDMA Channelization For New York Beam, Aggregate Rate - 5000 Mbps, 46 Beams. (N.Y. Rate ≈ 773 Mbps)

A further level of simplification would permit the receive channelizing unit to be broadband, which would result in transferring more transponder front-end noise to the downlink. Spare channelizing units are collected into a pool of switched spares so that they may be shared when required, even at the expense of additional satellite burden due to increased switch complexity.

The quantities of preassigned units are shown in Table 4.1-7. Clearly, the complexity of the switch matrix will be greatly reduced by preassignment. Note however, that spares are to be switched and this tends to expand the switch matrix again. The switch matrix dimensions are determined by adding the "sub-total switched" and the "total spares" columns in Table 4.1-7. Before considering the total spacecraft burden due to the channelizing units, the channelizing units and sections of the switch matrix are integrated to take advantage of common structure and shielding. This also eliminates many coaxial cables and connectors.

Switch Matrix Requirements and Integration With Channelizing Units

Comparisons of prevailing and projected switch matrix technologies have been made to define the applicable switch matrix techniques. For maximum channel bandwidths of 26 MHz and minimum bandwidths of 1.0 MHz, the lightest weight and power approach is CMOS/SOS LSI.* Implementation of CMOS/SOS switches at a center frequency of about 70-200 MHz results in a switch that is lightweight and has low-power consumption. CMOS/SOS FET technology will be readily available in the 1987 time period. Competitive technologies are summarized in Table 4.1-12.

For small numbers of channels, single stage crossbar switches remain a simple approach that is conservative, requires only simple switching algorithms and consumes relatively low power. However, as the number of switched channels increases, the need for an approach that conserves power and weight becomes evident. Multistage switches can reduce the number of crosspoints required and provide alternate routing through the switch matrix. However, the number of crosspoints encountered in traversing the switch increases directly as the

* B. J. Cory, "30/20 GHz Satellite Switching Matrix Development, Task II, Alternate Switch Matrix, 1987 Technology," Final Report, Report Number 1-5-GE-1-T2, Contract Number 3-22500, March 10, 1981.

Table 4.1-12. Tradeoff Matrix of Baseband Switch Candidates

Switch Candidates	Optical Optoelectronic Switch Hewlett Packard (HP5082-4203 PIN Photodiode)	DMOS Switch (Signetics SD214/SD215)	Low Loss Mesa Beam Lead PIN Diode (Hewlett Packard HPND-4001)	CMOS/SOS Switched Dual Gate Amplifiers (Estimated for 1987)
Isolation	>70 dB	~20 dB @ 100 MHz	~32 dB	~62.1 dB
Insertion Loss/ Gain	--	--	~0.19 dB	~+10 dB
Gain Slope Isolation Slope	6 dB/Octave --	-- --	0 dB 6 dB/Octave	-- --
Frequency Response	10 - 200 MHz 0 - 1 GHz *	0 - 100 MHz	~33 MHz - 10 GHz	550 MHz Min.
Bias Current Requirement	I_F = 9,20 mA	I_{ON} = 40 mA Max. I_{OFF} = ~1 nA	I_{ON} = 1 - 10 mA I_{OFF} = 0 (1)	~5 - 10 mA
Bias Voltage Requirement	V_R = 26 V @ "ON" State with 50 Ohm Load V_{R*} = -20 V	$V_{DD} \leq$ 10 V	V_{ON} ~ +1 V V_{OFF} ~ -10 V (2)	~2 - 4 V
Drive Current	--	I_{GB} = 10 μA Max.	See (1)	Negligible
Drive Voltage	--	± 15 V	See (2)	~4 V
Drive Power	90 μW from Laser	--	--	Negligible
Max. RF Signal Level	--	± 10 V	~1.6 W to 4 W	-10 dBm
Power Consumption	$P_{ON} \leq$ 15 mW	--	~ 8.75 mW - 100 mW	~ 20 mW
Switching Speed	<1 nsec*	$t_{OFF} \leq$ 10 nsec $t_{ON} \leq$ 1 nsec	$\leq$ 10 nsec	Pico-second Range
Noise Figure	--	--	--	3 - 4 dB
Linearity	--	--	Good	Good
Switch Reliability	Good	Good	Good	Good
LSI Compatibility	No	Yes	Yes	Yes
Architecture Compatibility	All	All	All	All
Bandwidth	--	~ 1 GHz	Multi-octave; depends on bias	--
Switch Package Vol.	Large	Very Small	Very Small	Very Small

number of stages. When compared to a single stage crossbar, the multistage (Clos) switch requires a more complex control algorithm. Since the control of the SS-FDMA switch will be on the ground, the additional software is not a significant factor.

A significant feature of the switch matrix is the number of crosspoints. A single stage crossbar requires N x M crosspoints, where N is the number of input lines and M is the number of output lines. Several implementations of a three stage switch are compared with a single-stage crossbar switch in Table 4.1-13. The Clos switch employs a submatrix at each stage. If the submatrix has a large number of entry lines, n, it becomes efficient when the switch is large. When n is small, the switch is relatively efficient for a small number of channels, but, is not unduly penalized for large numbers of channels. A practical size for the submatrix is n = 8 for less than 295 inputs, however, as the switch size increases, a submatrix size N=16 rapidly becomes more efficient. Because of the extreme complexity of the switch matrix, considerable weight and power can be saved if the switch matrix is partitioned by data rate. This results in a smaller number of switch crosspoints overall, as is demonstrated in Table 4.1-14. That table shows the trade regions between crossbar and multistage non-blocking switches and demonstrates how rapidly the number of switchpoints (crosspoints) increases with data rate in the SS-FDMA System. It clearly shows when to use crossbar or clos-type switch architecture, the size of the switch submatrix to choose, and the impact of large scale integration of the CMOS/SOS switch with the MMIC devices. Even though the aggregate data rate is high, the total switch size remains moderate, a direct result of partitioning the switch functions to the various levels of bandwidth.

While the switch is partitioned into more manageable units, the channelizing units can also be integrated with the switch assemblies. Channelizing unit integration occurs after the fourth downconverter (third D/C for 40 Mbps channels) of Figure 4.1-12, so that all power division and fanouts occur within the switch matrix. For the New York beam, this saves the weight of 115 sections (128-13) of coaxial cable and 230 connectors on the input side alone. Since the partitioning is on the basis of equal data rate channels and all beams are sized for equal uplink and downlink, all earth stations with equal capacity have the ability to be interconnected to any other earth station of the same capacity.

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Table 4.1-13. Summary of Switch Requirements for Three Quantization Levels with Pre-Assignment

Aggregate Rate (Mbps)	Switch Inputs		Total Switched	Switchpoints In Crossbar Configuration	Switchpoints in A Clos 3-Stage Non-Blacking Configuration	
	Switched	Spares			n = 8	n = 16
500	46	218	264	69,696	24,255	24,808
1000	54	221	275	75,625	25,975	26,208
2000	66	229	295	87,025	29,247	28,829
5000	173	226	439	192,721	58,339	50,556
10,000	272	297	569	327,761	92,951	74,484
15,000	376	328	704	495,616	137,280	103,664
20,000	409	342	751	564,001	154,718	114,859
40,000	569	388	957	915,849	243,362	170,238

$X = N(2n-1)[2+(N/n^2)]$, the number of crosspoints in a Clos Symmetrical Three-Stage switch

n = The number of ports at each input node

N = The total number of input ports.

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Table 4.1-14. Complexity Trade For Partitioned Switch Matrix and Integrated Channelizing Units (SS-FDMA)

AGGREGATE RATE (Mbps)	CHAN.	SPARES	TOTAL	NO. OF CROSSPOINTS: XBAR + 20% SPARES	CLOS 3-STAGE $\eta = 8$	CLOS 3-STAGE $\eta = 16$	SWITCH WEIGHT (POUNDS)	SWITCH POWER (WATTS)	SWITCH WITH INTEGRATED CHANNEL UNITS WEIGHT (POUNDS)	SWITCH WITH INTEGRATED CHANNEL UNITS POWER (WATTS)
	40 Mbps									
500	0	0	0	0	0	0	–	–	–	–
1000	0	0	0	0	0	0	–	–	–	–
2000	0	0	0	0	0	0	–	–	–	–
5000	4	2	6	44	192	372	1 (MIN)	0.3	1.125	2.5
10,000	24	8		1228	1200	2168	1.7	8.2	5.7	21.2
15,000	47	14	61	4466	2703	4233	3.7	18.5	11.3	43.9
20,000	80	28	108	13,997	5874	8109	8.2	40.9	21.7	84.1
40,000	240	74	314	176,215	32,529	31,408	43.3	214.8	82.6	344.4
	6.176 Mbps									
500	0	0	0	0	0	0	–	–	–	–
1000	8	3	11	146	359	697	1 (MIN)	1.0	2.4	5.3
2000	20	11	31	1154	1156	2039	1.6	7.9	5.5	16.3
5000	60	38	98	11,525	5191	7239	7.2	35.5	19.5	67.9
10,000	97	82	179	38,450	12,880	14,978	17.8	88.1	40.2	140.5
15,000	135	125	260	81,120	23,844	24,306	32.3	161.7	65.1	234.6
20,000	135	125	260	81,120	23,844	24,306	32.6	161.7	65.1	234.6
40,000	135	125	260	81,120	23,844	24,306	32.6	161.7	65.1	234.6
	1.544 Mbps									
500	46	218	264	83,636	24,255	24,808	33.5	165.9	66.5	190.7
1000	46	218	264	83,636	24,255	24,808	33.5	165.9	66.5	190.7
2000	46	218	264	83,636	24,255	24,808	33.5	165.9	66.5	190.7
5000	109	226	335	134,670	38,353	34,360	47.4	236.0	89.3	293.9
10,000	151	207	358	153,797	40,779	37,716	52.1	258.0	96.9	339.5
15,000	194	189	383	176,027	45,871	41,510	57.3	283.9	105.2	388.7
20,000	194	189	383	176,027	45,871	41,510	57.3	283.9	105.2	388.7
40,000	194	189	383	176,027	45,871	41,510	57.3	283.9	105.2	388.7

- WEIGHT OF THE SWITCH MATRIX = 1.38×10^{-3} POUNDS/CROSSPOINT
- POWER REQUIRED BY THE SWITCH MATRIX = 6.84×10^{-3} WATTS/CROSSPOINT
- WEIGHT OF CHANNELIZING UNITS IS 1 OZ. EACH, OR 2 OZ. FOR THE COMBINATION OF UPLINK AND DOWNLINK
- POWER FOR CHANNELIZING UNITS = 270m W/ACTIVE CHANNEL X2 FOR UPLINK + DOWNLINK

In the switch matrix study performed by General Electric for the 1987 time frame, the characteristics of an IF switch and a baseband switch were compared (See Table 4.1-15). The baseband switch operates to frequencies of about 120 MHz now and is projected to operate to frequencies of about 700 MHz by 1987. Therefore, the "baseband" switch approach, using CMOS/SOS LSI is directly useable at the low value of the IF we have chosen and can, with reasonable confidence be employed at IF center frequencies of 300 to 400 MHz should it become necessary to support wider bandwidths.

Downconverter, Upconverter and Local Oscillator Requirements

The First Downconverter (D/C) and IF preamplifier are located in the receive MBA, and each weighs 0.18 pounds and requires 0.75 watts for IF amplifier and mixer bias power. Weight and power requirements for this internally redundant unit are included with the receive antenna burden.

The Receiver/Second Downconverter has an X-band input signal and L-band output. It will use a conventional GaAs FET Microwave Integrated Circuit (MIC) structure as defined in Table 4.1-16. Passive coupling rather than switching is used for redundancy combining.

The Third Downconverter operates at L-band and is a good candidate for a Monolithic Microwave Integrated Circuit (MMIC) approach. With about 50% more complexity, but, equivalent amplification requirements to the channelizing unit discussed, the weight of the MMIC unit should be approximately 2.25 oz. or 0.14 pounds, and the power will be about 300 MW. There are three per beam, therefore, the weight and power required for the third downconverter is:

Weight third D/C = $0.14\ N_B \times 3 = 0.42\ N_B$ Pounds.
Power third D/C = $0.3\ N_B \times 3 = 0.9\ N_B$ Watts.

The quantity of Fourth Downconverters on any one beam is dependent upon the traffic analysis and the subsequent assignment of traffic to that beam, but, traffic assignment is partly subjective. Therefore, Table 4.1-17 is used to determine the number of fourth downconverters required for the system. For convenience, the number of fourth downconverters will be established as one per 10 channelizing units, including spares. Hence,

Table 4.1-15. Comparison of IF and Baseband Switches for the 1987 Time Frame

Parameter	Large IF Switch	Baseband Switch
Matrix size	96 x 96	Same
Connectivity	Any of the inputs to any of the outputs. One for one.	Same
Reconfiguration rate	2 microseconds	Same
Switching time	10 nanoseconds	10 nanoseconds
Computer interface	61 lines	Same
Electrical performance		
Input signal level	-5 + 5 dBm	-6 + 5 dBm
Frequency spectrum	8 + 0.25 GHz	25 to 500 MHz
Flatness	± 1 dB	+ 1 dB
Phase linearity	∓ 5^{o} max.	+ 5^{o} max.
Isolation	40 dB all inputs Equal signal strength	42 dB all inputs Equal signalstrength
Insertion loss	30 dB max.	32 dB max.
Noise	35 dB below output signal level	35 dB below output signal level
Intermodulation (3rd order)	- 30 dB Two equal tones	-34 dB Two equal tones
Impedance (input/output)	50 ohms	Same
VSWR (input/output)	1.2:1	Same
Power consumption	129.3 watts (1.4×10^{-2}W/XPT)	63 watts(6.84×10^{-3} W/crosspoint)
Reliability (10 year mission)	0.76867	0.91019
Mechanical		
Size	12 x 12 x 2 in.	10.5x10.5x3.5 in.
Weight	11.5 lbs (1.25×10^{-3}lbs per crosspoint)	12.7 lbs(1.38×10^{-3} lbs/crosspoint)
Scaleability beyond 96x96	Feasible with degraded performance	Same
Growth to larger bandwidth	Same as above	Same
Operating Temperature	$-10^{o}C$ to $+50^{o}C$	Same

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$$N_{4th\ D/C} = \frac{ch + spares}{10}$$

Implementation of the fourth downconverter will be in the same manner as the third downconverter and the weight and power requirements are assumed to be identical. Therefore, the total fourth downconverter weight and power is given by:

$$W_{4th\ D/C} = 0.14 \frac{N_{ch} + N_{spares}}{10} \text{ Pounds}$$

$$P_{4th\ D/C} = 0.3 \frac{N_{ch} + N_{spares}}{10} \text{ Watts}$$

Table 4.1-16. Receiver/2nd Downconverter Weight and Power Estimate (One/Beam)

Item	Quantity Required Active	Redundant	Unit Weight (Pounds)	Unit Power* (Watts)	Weight (Pounds)	Power (Watts)
Bandpass Filter	1	-	0.05	-	0.05	-
Low Pass Filter	1	1	0.02	-	0.04	-
Mixer	1	1	0.03	-	0.06	-
Amplifier, Local Oscillator	1	1	0.03	0.15	0.06	0.15
Amplifier, I.F.	2	2	0.03	0.15	0.12	0.30
Coaxial Cable(Feet)	0.5	-	0.1	-	0.05	-
Shields, Brackets Substrates(Pounds)	0.1	-	0.2	-	0.2	-
Hybrid Couplers	2	-	0.05	-	0.1	-
Weight & Power for Each Beam					0.68	0.45

*Redundant Components Not Powered

Weight = $0.68N_B$ Pounds

Power = $0.45N_B$ Watts

Local oscillator requirements: The payload diagram given in Figure 4.1-12 requires generation of the following local oscillator signals.

1. Receiver

   a. L.O. #1 - 9.5 GHz*
   b. L.O. #2 - 8.5 GHz
   c. L.O. #3 - 1955 MHz
   d. L.O. #4 - 1000 MHz
   e. L.O. #5 - 1000 MHz (Supplied by L.O. #4)
   f. L.O. #6 - UHF Comb Generator, 40 MHz Spacing
   g. L.O. #7 - UHF Comb Generator, 10 MHz Spacing
   h. C.L.O.40 - UHF Comb Generator, 26 MHz Spacing
   i. C.L.O.6 - UHF Comb Generator, 4 MHz Spacing
   i. C.L.O.1.5 - UHF Comb Generator, 1 MHz Spacing

2. Transmitter

   a. C.L.O.40 - Use Receiver C.L.O.40
   b. C.L.O.6 - Use Receiver C.L.O.6
   c. C.L.O.1.5 - Use Receiver C.L.O.1.5
   d. L.O. #8 - Use Receiver L.O. #3
   e. L.O. #9 - Use Receiver L.O. #4
   f. L.O. #10 - Use Receiver L.O. #5 (or 4)
   g. L.O. #11 - Use Receiver L.O. #2
   h. L.O. #12 - 500 MHz Crystal Oscillator
   i. L.O. #13 - Use Receiver L.O. #1

By analyzing the frequency plan so that the receiver local oscillators can be employed, only one other source is required, a 500 MHz crystal oscillator. Weight and power requirements for the local oscillators and the distribution networks are derived in Table 4.1-17. Local oscillator weight and power are sensitive to the number of channels.

$$W_{L.O.} = [12.6 + 0.63\ N_B + 0.206\ N_{ch}/10]\ \text{Pounds}$$

$$P_{L.O.} = [35.0 + 0.539\ N_B + 0.2\ N_{ch}/10]\ \text{Watts}$$

N_B = No. of Beams

N_{ch} = No. of Active Channels (Excludes Spares, See Table 4.1-17)

Three transmitter upconverters are required for each beam. Weight and power requirements are identical to the third downconverter used in the receiver. Hence the weight and power requirements of the transmitter upconverter are:

*Requires Multiplication x 2 if subharmonically pumped mixer is not available.

Table 4.1-17. Local Oscillator Requirements, SS-FDMA Payload

Item	Quantity Required Active	Redundant	Unit Weight (Pounds)	Unit Power (Watts)	Total Weight (Pounds)	Power (Watts)
Frequency Standard	1	1	0.8	1.5	1.6	1.5
9.5 GHz Local Iscillator, L.O. #1 & L.O. #13	1	1	1.25	11.0	2.5	11.0
9.5 GHz Amplifier	1	1	0.1	0.2	$0.02N_B/13$	$0.2N_B/13$
9.5 GHz Power Divider & Coax	1	--	0.106	--	$0.106N_B/13$	--
8.5 GHz Local Osc. L.O. #2 & L.O.#11	1	1	1.25	11.0	2.5	11.0
8.5 GHz Amplifiers	2	2	0.1	0.2	$0.4N_B/13$	$0.4N_B/13$
8.5 GHz Power divider & Coas	2	--	0.106	--	$0.212N_B/13$	--
1955 MHz, L.O. #3 & Lo.O. #8	1	1	0.5	3.0	1.0	3.0
1955 MHz Amplifiers	1	1	0.1	0.2	$0.2N_B/13$	$0.2N_B/13$
Power Divider & Coax	2	--	0.106	--	$0.212N_B/13$	--
1000 MHz L.O. #4, 5, 9 & 10	1	1	0.5	3.0	1.0	3.0
1000 MHz Amplifier	4	4	0.1	0.2	$0.8\ N_B/13$	$0.8\ N_B/13$
Power Dividers & Coax	4	--	0.106	--	$0.424N_B/13$	--
500 MHz Oscillator, L.O. #12	1	1	0.5	3.0	1.0	3.0
500 MHz Amplifier	1	1	0.1	0.2	$0.2N_B/13$	$0.2N_B/13$
Power Dividers & Coax	1	--	0.106	--	$0.106\ N_B/13$	--
UHF Comb Generator, L.O. #6, 40 MHz Spacing	1	1	0.3	0.5	0.6	0.5
UHF Amplifiers	1	1	0.1	0.2	$0.1N_B$	$0.2N_B$
Power Divider & Coax	1	--	0.106	--	$0.106\ N_B$	--
UHF Comb generator, L.O.#7,10 MHz Spacing	1	1	0.3	0.5	0.6	0.5
UHF Amplifier	1	1	0.1	0.2	$0.1N_B$	$0.2N_B$
Power Divider & Coax	1	--	0.106	-	$0.106\ N_B$	$0.2N_B$
UHF Comb Generator, L.O 40, 26 MHz spacing	1	1	0.3	0.5	0.6	0.5
UHF Comb Generator, CLO_6 4 MHz Spacing	1	1	0.3	0.5	0.6	0.5
UHF Comb Generator, $CLO_{1.5}$ 1 MHz Spacing	1	1	0.3	0.5	0.6	0.5
UHF Amplifiers, 40 Mbps channels	1	1	0.1	0.2	$0.1(N_{40}/10) \geq 0.1)$	$0.2(N_{40}/10)(\geq 0.2)$
UHF Amplifiers, 6 Mbps Channels	1	1	0.1	0.2	$0.1(N_6/10)(\geq 0.1)$	$0.2(N_{1.5}/10)(\geq 0.2)$
UHF Amplifiers, 1.544 Mbps channels	1	1	0.1	0.2	$0.1(N_{1.5}/10\ (\geq 0.1)$	$0.2(N_{1.5}/10)(\geq 0.2)$
Power Dividers & Coax, 40 Mbps Channels	1	--	0.106	--	$0.106N_B/N_{40}/10)$	---
Power Dividers & Coax 6 Mbps Channels	1	--	0.106	--	$0.106N_B/N_B/10)$	--
Power Dividers & Coax, 1.544 Mbps Ch.	1	--	0.106	--	$0.106N_B(N_{1.5}/10)$	--

$$W_{L.O.} = 12.6 + 2.87\ N_B/13 + 0.412\ N_B + (0.1N_{40}/10 + 0.1\ N_6/10 + 0.1N_{1.5}/10 + (0.106\ N_{40}/10 + 0.106\ N_6 + 0.106\ N_{1.5}/10)$$

$$W_{L.O.} = (12.6 + 0.63\ N_B + 0.021\ N_{CH})\ \text{Pounds}$$

N_B = No. of Beams
N_{Ch} = No. of Active Channels (excludes spares)

$$P_{L.O.} = 35 + 1.8\ N_B/13 + 0.4\ N_B + (0.2\ N_{40}/10 + 0.2\ N_6/10 + 0.2\ N_{1.5}/10$$

$$P_{L.O.} = 35 + 0.539\ N_B + 0.02\ N_{Ch}\ \text{Watts}$$

$W_{txu/c} = 0.42\ N_B$ Pounds

$P_{txu/c} = 0.9\ N_B$ Watts

Weight and power requirements for the redundant final upconverter and driver amplifier assembly are given in Table 4.1-18.

Transmitter Weight and Power Requirements

Transmitter output circuit element weight is contained in Table 4.1-19, and the transmit antenna requirements were detailed in Table 4.1-4.

TWTA weight and power requirements are a function of the required EIRP. It has been assumed that one for two redundancy will be required for TWTAs. It has also been assumed that TWTA design for the CPS will benefit from economics of scale and will have progressed to the point where three TWTAs will weigh the equivalent of two TWTAs produced by 1982 technology, including the Electronic Power Converter (EPC). Hence, each TWTA, including its pro-rata share of the redundant burden will weigh

$$W_{TWTA} = 0.106\ W_{RF} + 6 \text{ Pounds}$$

and will operate at 40% efficiency. Figure 4.1-13 illustrates the TWTA weight and power requirements.

Power amplifier requirements are derived in Table 4.1-20, normalized to a one meter diameter earth station antenna and a data rate of 1.544 Mbps. Values are shown for Rain Zone D and 0.995 availability. Data for adjusting these values to other rain zones and availabilities have been summarized in Section 3.2.6.

SS-FDMA Payload Weight and Power

Weight and power requirements for the SS-FDMA system reflect the following:

1. Bandwidth quantization to three levels corresponding to data rates of 1.544, 6.176 and 40 Mbps.
2. Use of advanced Monolithic Microwave Integrated Circuits with proven capability.

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Table 4.1-18. **Transmitter Upconverter and Driver Assembly, Weight and Power Estimate**

ITEM	QUANTITY ACTIVE	QUANTITY REDUNDANT	UNIT WEIGHT (POUNDS)	UNIT (1) POWER (WATTS)	TOTAL WEIGHT PER BEAM (POUNDS)
Summing Network	1	--	0.05	--	0.05
Hybrid Coupler	1	--	0.05	--	0.05
Amplifier, IF	1	1	0.03	0.15	0.03
Mixer	1	1	0.03	--	0.03
Amplifier, Local Osc.	1	1	0.03	0.15	0.03
Bandpass Filter	1	1	0.05	--	0.05
Amplifier, Driver	1	1	0.25	0.4	0.25
Coaxial Cable	1 ft.	-	0.1	-	0.1
Waveguide	1 ft.	--	0.09	--	0.09
Shields & Brackets	0.2 lbs.	--	0.2	-	0.2
Redundancy Switches(2)	1	--	0.1	-	0.1
Total Power and Weight Per Beam				0.7	0.98

(1) Redundant components not powered
(2) Redundancy switches require 4.2 watts during switching, but, are switched one at a time

Table 4.1-19. Transmitter Output Circuits

ITEM	QUANTITY	UNIT WEIGHT POUNDS	UNIT POWER (WATTS)	WEIGHT/BEAM POUNDS
Waveguide	2 ft	0.09	--	0.18
Bandpass Filter	1	0.1	--	0.1
Redundancy Switch (TWTA)	2	0.4	(2)	0.8
Isolator (TWTA)	1	0.3	--	0.6
TOTAL				1.68

(1) TWTAs will be redundant on the basis of 1 redundant TWTA for each two operating TWTA's (1:2 redundancy)
(2) 4.2 watts when switching

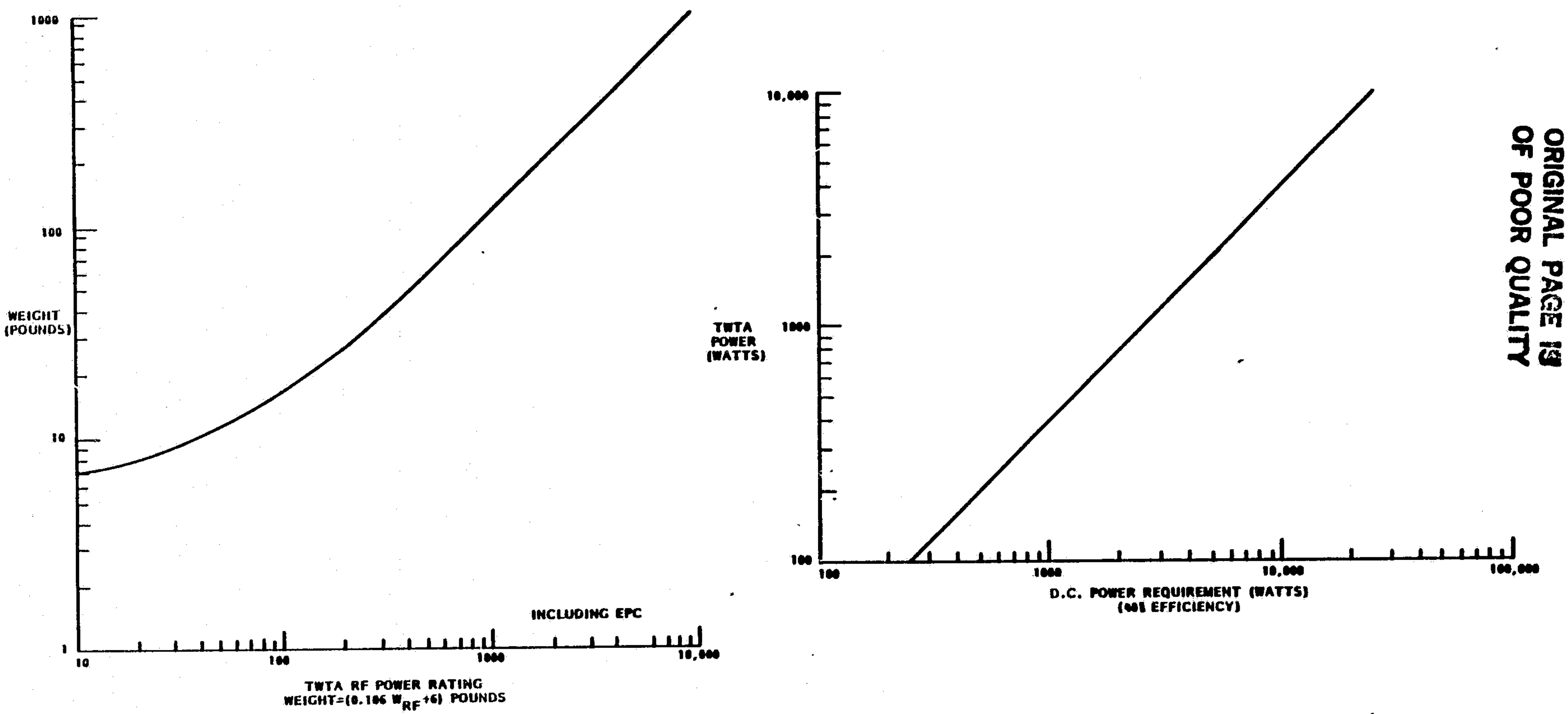

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Figure 4.1-13. TWTA Weight and Power Requirements

Table 4.1-20. SS-FDMA Power Amplifier Requirements (0.995 Availability, Zone D) - Normalized to a One Meter Earth Station and a Date Rate of 1.544 Mbps

- EIRP (0.995) 52.8 + 10 Log DR/1.544 Mbps (where DR is the data rate)
- 6-dB output backoff for C/IM $\geq$ 18.5 dB
- Transponder Loss Budget

- Waveguide	0.3 dB
- Bandpass filter	0.5
- Isolator	0.3
- Redundancy Switch	0.3
- Antenna Waveguide	0.2
- Antenna/Transponder Mismatch Loss	0.3
Transmitter Losses, L_T =	1.9 dB

- TWTA Power Required is: P_{TWTA} = EIRP - G_T + L_T

P_{TWTA} (0.995) = 54.7 dBw + 10 Log DR/1.544 Mbits/sec - G_T
and G_T is the transmit antenna contour gain in dBi.

$G_T = 39.2 - 20 \log \alpha^{\circ}$

Earth Station has a 1 meter antenna
Subtract (20 log D) dB for Earth Antenna D meters in diameter

Number of Beams	Cell Diameter (Degrees) α	G_T (dBi) at Adjacent Cell Contour	TWTA Power (dBw) Per T-1 Carrier (1.544 Mbps)
13	1.21	37.54	17.16
19	1.0	39.2	15.5
32	0.77	41.47	13.23
46	0.64	43.08	11.62
68	0.53	44.71	9.99
100	0.44	46.33	8.37
178	0.33	48.83	5.87

For 0.999 Availability - add 5.6 dB to TWTA Power
For 0.9995 Availability - add 12.9 dB to TWTA Power
Saturated output of TWTA is 6 dB higher

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3. Application of partitioned switch matrices using CMOS/SOS LSI techniques.

4. Integration of Switch Modules and channelizing units to eliminate large quantities of coaxial cable and connections.

Payload weight and power equations are summarized in Table 4.1-21. Figure 4.1-14 illustrates SS-FDMA payload weight and power requirements for the CPS SS-FDMA system, subject to the constraints of Table 4.1-21.

4.1.2 SS-TDMA/FIXED BEAM PAYLOAD CONCEPT

The SS-TDMA /Fixed Beam system payload concept, illustrated in Figure 4.1-15 is based on multiple, fixed beam antennas, on-board IF switching for time reallocation and rate diversity for fade compensation. Signalling and switching is similar to that of SS-FDMA, using a Common Signalling Channel (CSC) which is part of the burst architecture. To minimize earth station cost the lowest possible burst rates are desireable to reduce the requirements for earth station antenna size, HPA power levels and modem complexity. However, actual burst rates of 20, 100 and 256 Mbps were employed to minimize the satellite channelization.

Routing through the SS-TDMA/Fixed Beam transponder is dependent upon the time at which the data burst reaches the satellite. The IF switch provides connectivity between the receive and transmit beams in the appropriate sequence so as to route the data from each uplink beam to the desired downlink beams. The interconnection time between beams can be varied to trade data time for access, synchronization and signalling time and may be on the order of a few microseconds to about 1000 microseconds.

As with SS-FDMA, multiple contiguous beams are employed requiring the division of the available bandwidth among the beams to achieve spatial isolation and reduce co-channel interference. Since multiple TDMA burst rates are used, the channels in each beam will be frequency division multiplexed. The system is basically comprised of several parallel bent-pipe transponders interconnected by the IF switch and does not employ demodulation on the spacecraft. Through the use of multiple burst rates earth stations can be tailored to the requirements of the users. Rain fade compensation is achieved by a combination of rate diversity and system link margin. Also earth station space (or site) diversity can be added. Rain margins should be tailored to the specific climatic region and the operational elevation angle at the terminal location.

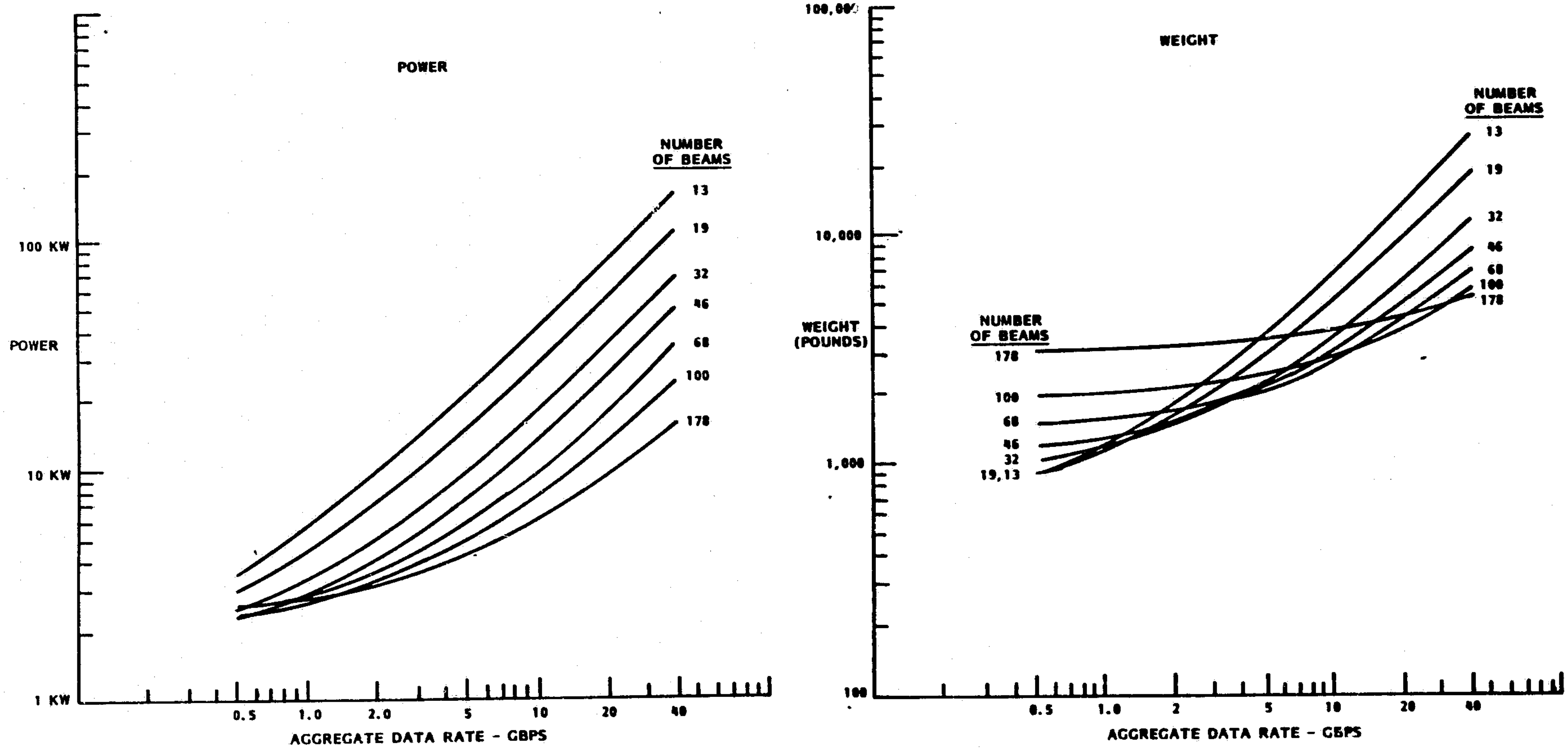

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Figure 4.1-14. SS-FDMA System Payload Weight and Power
3 Levels of Bandwidth Quantization
(5M ES, Rain Zone D, 0.995 Availability)

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Table 4.1-21. Summary of SS-FDMA Weight and Power Equations

ITEM	QUANTITY	TOTAL WEIGHT (POUNDS)	TOTAL POWER (WATTS)
RECEIVE ANTENNA	1/SATELLITE	$.87 N_B + .8 A_R + 3.37 D_R + 15.$	$0.75\ N_B$
2nd D/C (RECEIVER)	1/BEAM	$0.68\ N_B$	$0.45\ N_B$
3rd D/C	3/BEAM	$0.42\ N_B$	$0.9\ N_B$
4th D/C	$(N_{ch} + N_{spares})/10$	$.14 x (N_{ch} + N_{spares})/10$	$0.3 x (N_{ch} + N_{spares})/10$
REC/TRANS CH. UNITS AND SWITCH	See TABLE 4.1-14	See TABLE 4.1-14	See TABLE 4.1-14
REC/TRANS CH, UNITS PREASSIGNED	See TABLE 4.1-7	$0.045\ N_{pach}$	$0.27\ N_{Pach}$
CONTROL & SIGNALLING	1	4	4
LOCAL OSCILLATOR	See TABLE 4.1-17	$12.6 + .63 N_B + .021 N_{ch}$	$35 + .54 N_B + .02 N_{ch}$
TRANS. UPCONVERTER	3/BEAM	$0.42\ N_B$	$0.9\ N_B$
FINAL U/C AND DRIVER ASSEMBLY	1/BEAM	$0.7\ N_B$	$0.98\ N_B$
TRANSMITTER OUTPUT CIRCUITS	1/BEAM	$1.68\ N_B$	- - -
TWTA	1/BEAM	$EIRP^* x\ 9.72 x 10^{-4}\ DR/N_B + 6N_B$	$EIRP^* x\ 5.73 x 10^{-3}\ DR/N_B$
TRANSMIT ANTENNA	1/SATELLITE	$.99 N_B + .8 A_R + 3.37 D_R + 15.$	- - -

*per TABLE 4.1-20
(not in dB; correct for
earth station antenna diameter)

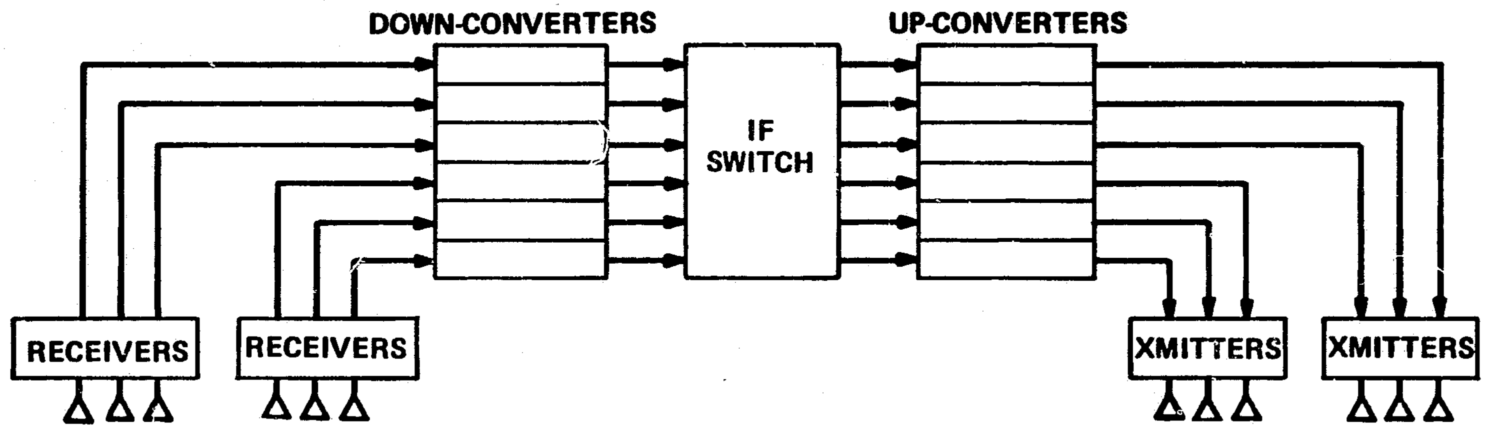


Figure 4.1-15. SS-TDMA/Fixed Beam Concept

SS-TDMA/Fixed Beam Frame Characteristics

Each TDMA frame provides sufficient time for total beam connectivity. Each connectivity segment within the frame will be referred to as a subframe.

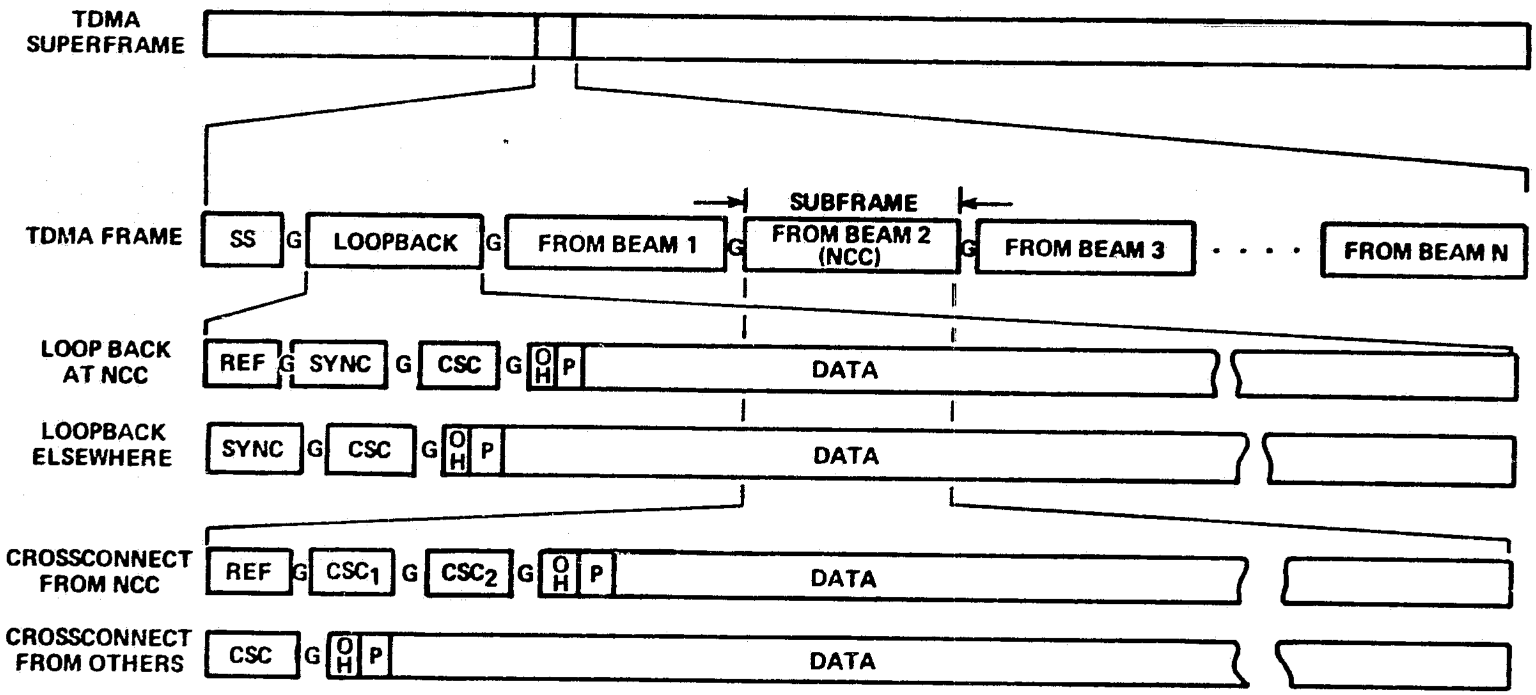
In addition to data bursts, the TDMA frame provides for service requests, signalling, commands, telemetry and synchronization. Synchronization, including burst phasing and timing, is a critical factor in TDMA frame utilization since it must be achieved between the satellite switch and all earth stations.

In addition to satellite and earth station burst synchronization, the user modems must acquire synchronization for bit timing and carrier recovery. The method of acquiring synchronization at these various levels is described in Figure 4.1-15 and in the following discussion.

At the beginning of the TDMA frame, a synchronization pulse is generated by the Satellite switch and processed by the Network Control Center (NCC) to achieve synchronization with the satellite switch. This period is denoted SS in Figure 4.1-16. After synchronizing with the Satellite switch, the NCC transmits a reference burst, alternately from the prime and the diversity sites, within each change in state of the switch. These reference bursts provide the earth stations with information needed to establish coarse synchronism with the Satellite.

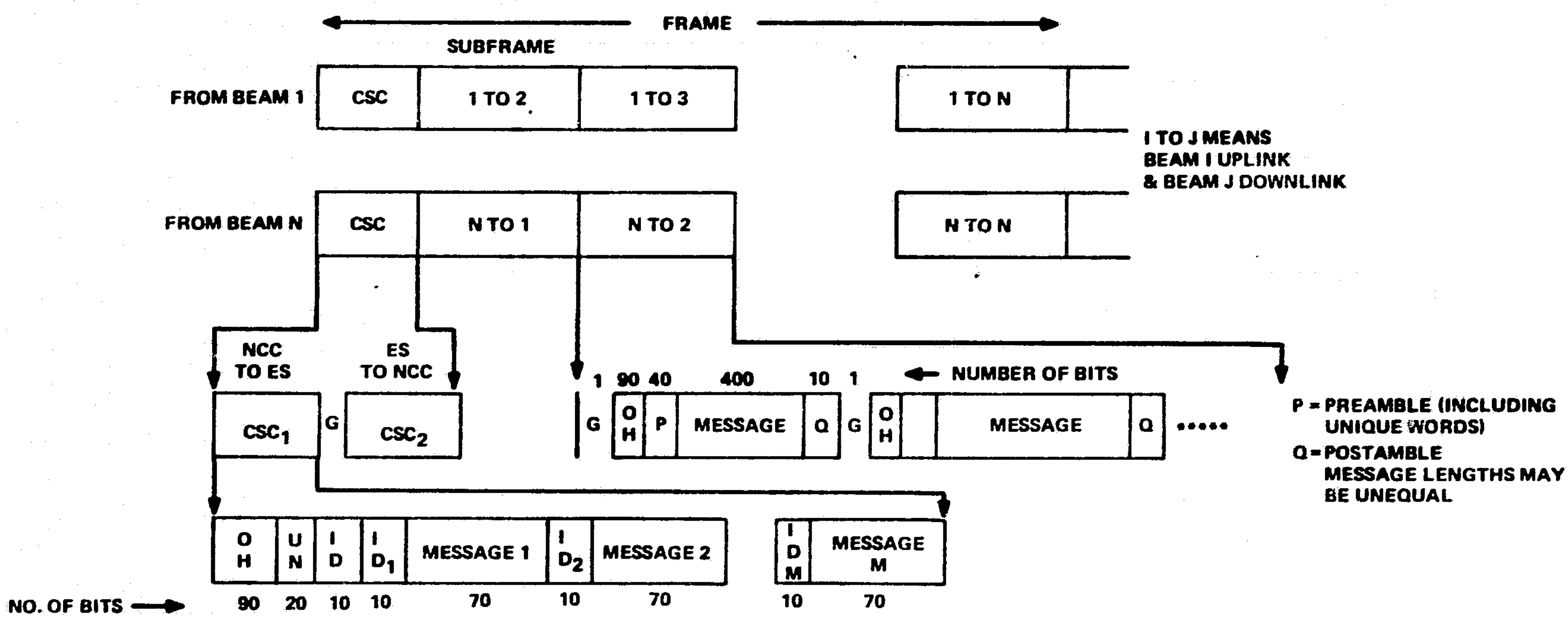
After this initial synchronization period, the satellite switch enters a loopback mode, wherein all uplink beams are connected to their own downlink beams. During this loopback mode, a synch window (SYNC) is provided, so that the earth stations can transmit a synchronizing burst to the spacecraft and have it returned in order to establish burst timing, or phasing, with respect to the switch cycle.

As a practical matter, we assume that loopback and subsequent earth terminal synchronization occurs over the Common Signalling Channel (CSC) and that the receive modem synch occurs during message preambles. A typical burst format plan that may be used as a basis for such a system appears in Figure 4.1-17. A preliminary allocation of bit periods has been made to each function to aid in estimating the frame efficiency. Whenever the required system capacity



O H	=	OVERHEAD FOR FREQUENCY, TIME, PHASE SYNC
SS	=	SATELLITE SWITCH SYNCHRONIZATION
LOOPBACK	=	IF SWITCH STATE WHICH CONNECTS STATIONS IN THE SAME BEAM
CROSSCONNECT	=	IF SWITCH STATE WHICH CONNECTS STATIONS IN DIFFERENT BEAMS
REF	=	ALTERNATES BETWEEN LOCAL AND DIVERSITY REFERENCE BURSTS
SYNC	=	USED FOR LOCAL BURST SYNCHRONIZATION DURING LOOPBACK
P	=	PREAMBLE AND UNIQUE WORD
DATA	=	DATA BURST
CSC_1	=	COMMON SIGNALLING CHANNEL FROM NCC TO EARTH STATIONS
CSC_2	=	COMMON SIGNALLING CHANNEL FROM EARTH STATIONS TO NCC

Figure 4.1-16. CPS Downlink Frame Structure



$^{O}_{H}$ = OVERHEAD FOR FREQUENCY, PHASE, TIME SYNC G = GUARD TIME

$^{U}_{N}$ = UNIQUE WORD (IDENTIFIES BURST)

$^{I}_{D_s}$ = IDENTIFIES NCC TRANSMISSION

$^{I}_{D_1}$ TO $^{I}_{D_M}$ = IDENTIFIES ES BEING ADDRESSED (IN CSC_2 IT IDENTIFIES TRANSMITTING ES)

*DOWNLINK MESSAGES INCLUDE COMMANDS, SIGNALLING (TIME SLOT ASSIGNMENTS, RINGING, BUSY, ETC), TIMING DATA

**UPLINK MESSAGES INCLUDE REQUESTED TELEMETRY, ALARM MESSAGES, SIGNAL (SERVICE REQUESTS)
CSC_1 & CSC_2 MESSAGES MAY NOT BE ADJACENT.
TOTAL FRAME TIME = N (MSG + 141 + 80) + 121

Figure 4.1-17. SS-TDMA Frame and Burst Formats

approaches the effective data transmission rate, another TDMA carrier will be required. Expansion of the frame diagram in the frequency domain is demonstrated in Figure 4.1-18.

Detailed bit (or time) allocations for all aspects of the timing and framing is not discussed, however, data burst length relative to total overhead will be investigated. The data burst time must be sufficiently long relative to the synchronizing and other overhead (OH) activities so that frame efficiency is relatively high - say on the order of 80-85% or more. Frame efficiency is defined in the following expression:

$$n = \frac{\text{Total data time in a frame interval}}{\text{Frame Interval}}$$

and plotted in Figure 4.1-19, parametric in the number of earth stations (and hence, message blocks) per subframe where each subframe represents a beam-to-beam interconnect. The results of Figure 4.1-19 shows that frame efficiency increases rapidly as the terminal population grows to about 10 terminals per subframe and is nearly asymptotic by the time 20 terminals are in the network frame. Also, note that frame efficiency can be substantially improved by assigning all CSC messages and earth station synchronizing functions to a separate carrier with only minor burden imposed on the earth station. Then, frame efficiency becomes virtually independent of the number of earth stations and is only dependent upon the make up of Guard Time, Preamble, Postamble and Message Overhead bits.

Characterization of the TDMA User Network

Before the SS-TDMA/Fixed Beam satellite payload characteristics can be formulated, the important characteristics of the TDMA user networks and the system constraints must be defined. An important set of parameters in the CPS concept is the number of facilities (Earth Stations) that will become CPS users as a function of system availability, cost, and the data rates each facility is expected to generate. Characteristics such as these have been derived and are summarized in Table 4.1-22 to 4.1-24 inclusive, for an aggregate data rate of 5 Gbps.

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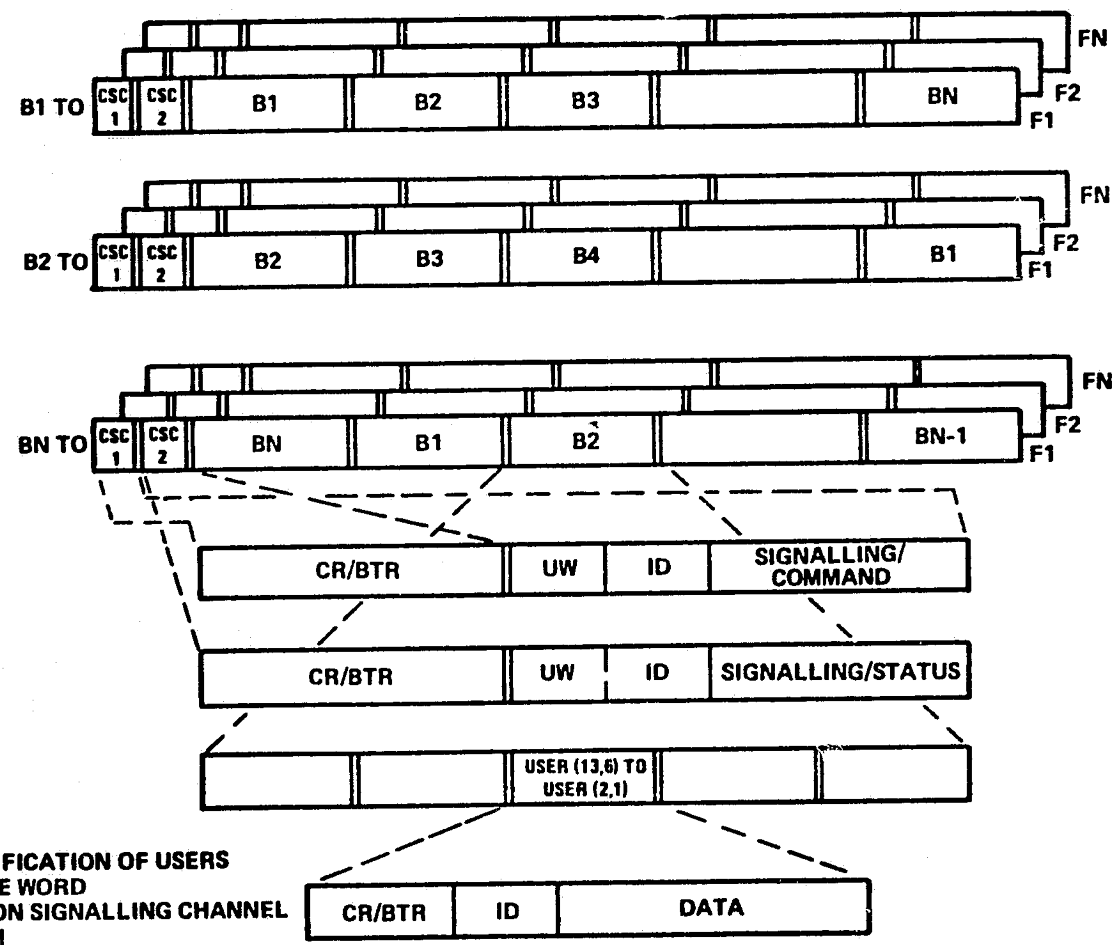

ID = IDENTIFICATION OF USERS
UW = UNIQUE WORD
CSC = COMMON SIGNALLING CHANNEL
Bi = i BEAM
Fi = iTH CARRIER FREQUENCY
CR = CARRIER RECOVERY
BTR = BIT TIMING RECOVERY

Figure 4.1-18. SS-TDMA/FDMA Frame Format (Time and Frequency Access)

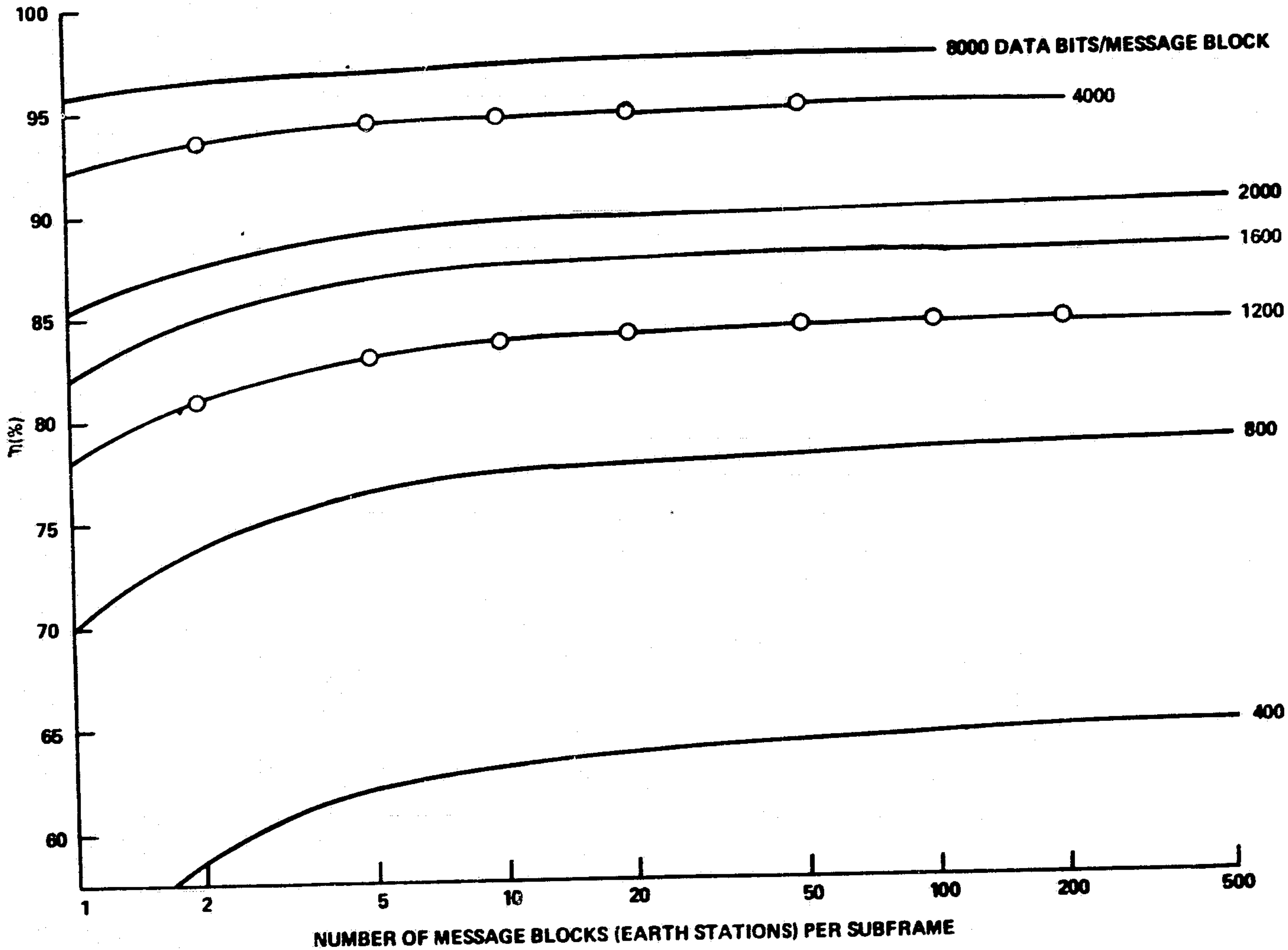

Figure 4.1-19. SS-TDMA Frame Efficiency for Various Burst Formats

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Table 4.1-22. Number of CPS User Facilities

User	Availability 99.5%	Availability 99.9%
Large Business	473	410
Small/Medium Business	794	629
Large Government Agencies	27	24
Municipalities	174	138
Institutions (Avg.)	110	108
Private Homes & Condominiums Concentration 1000:1	25	25
Total	1603	1334

- Year 2000
- Peak Aggregate traffic 5 Gbps
- Scaleable to a given peak capacity (in Gbps) "C" by (C/5) times value given above

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Table 4.1-23. CPS Services Per User Facility For 99.5% Availability

User	CPS Service						No. of Facilities* (Earth Stations) 0.995 Avail	Total Peak Capacity 0.995 Avail (Mbps)
	Voice 64 Kbps Circuits	Video Conf. 2 T_1 Ch	Video Info 4 T_1 Ch	Computer Message 56 Kbps Ckts	Computer Data 9600 BPS Ckts	Peak Capacity Per Fac Mbps		
Large Business	36	1	0	3	25	5.8 (4 T_1)	473	2743.4
Small/Medium Business	6	0	0	1	5	0.5 (T_1)	794	397.0
Large Government Agencies	50	1	1	5	50	13.2 (8.6 T_1)	27	356.4
Municipalities	6	0	0	1	5	0.5 ($<T_1$)	174	87.0
Institutions (Avg.)	16	1	1	3	25	10.7 (6.9 T_1)	110	1177.0
Private Homes & Condominiums Concentrated 1000:1	50	0	1	0	10	9.5 (6.2 T_1)	25	237.5
						TOTALS	1603	$\approx$ 5000

* One Earth Station is associated with each facility

Year 2000
Availability $\leq$ 99.5%
5000 Mbps Aggregate Rate

Table 4.1-24. CPS Service Per User Facility For 99.9% Availability

User	CPS Services						No. # Facilities* (Earth Stations) 0.999 Availability	Total Peak Capacity (Mbps) 0.999 Availability
	Voice 64 Kbps Circuits	Video Conf. (2 T-1 Channels)	Video Infor. (2 T-1 Channels)	Computer Message (56 Kbps Circuits)	Computer Data (9.6 Kbps Circuits)	Peak Capacity Per Facility (Mbps & T-1 Equivalents)		
Large Business	50	1	0	3	25	6.7 (4.4 T-1)	410	2747
Small/Medium Business	8	0	0	1	5	0.62 (< 1 T-1)	629	390
Large Government Agencies	76	1	1	5	50	14.9 (9.7T-1)	24	357.6
Municipalities	8	0	0	1	5	0.62 (<1 T-1)	138	85.6
Institutions	20	1	1	3	25	11.0 (7.1T-1)	108	1188.0
Private Homes and Condominiums Concentration 1000:1	50	0	1	0	10	9.5 (6.2T-1)	25	237.5
					Totals		1334	4920.1 ≅ 5000

* One Earth Station is associated with each facility

Year 2000
Availability ≥ 99.9%
5000 Mbps Aggregate Rate

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The number of CPS user facilities is given in Table 4.1-22. Given a bound on the number of earth stations, the next step is to estimate data rates and potentially, families of data rates that will permit the grouping of users into compatible networks. Note that precise data rate matching is not required since TDMA accesses can be subdivided by time division multiplexing the low rate users at the earth station (concentration), and then using local distribution networks such as CATV cable, optical or radio links, etc., to provide the distribution function.

Service requirements of the principal users and the total data generated by the various user groups are given in Table 4.1-23 and 4.1-24 for system availabilities of 0.995 and 0.999, respectively for the year 2000. These data show that useful rate quantization levels for the CPS when operated in TDMA would be on the order of 1 T1, 4 T1 and 10 T1 channels for 0.995 availability. Burst rates will be proportional to the effective rates given above, the overhead level and the number of earth stations in the network. For an aggregate rate of 5 Gbps, we will use 1603 earth stations (0.995 availability). Direct scaling to other aggregate data rates is applicable.

The overhead structure in Figure 4.1-17 is allocated herein on the basis of one Common Signalling Channel (CSC) interval (including CSC overhead) for each user message and overhead. Total overhead per frame includes the CSC message. For N earth stations in any frame, the distribution of frame time may be summarized in the following manner.

1. CSC subframe = (90 + 20 + 10) + N(10 + M) bits where M = the message length and N equals the number of earth stations.

2. Message Subframe = N(1 + 90 + 40 + M + 10) bits.

3. The number of Message Groups = the number of CSC groups = the number of Earth Stations.

4. Total bits/frame are

$$F_b = [120 + N\,(10 + 70)]_{CSC} + [N\,(141 + M)]_{MSG}$$

   where the message length, M, can be a variable.

5. Efficiency of the system increases with increasing N and M, subject to practical constraints on the burst rate.

6. When the signalling alphabet is of higher order than binary, the word "symbol" may be substituted for the word "bit", depending upon whether references is made to the channel rate or to the information rate.

Given the above definitions, we can calculate the percent of the frame time actually allocated for data, which is the frame efficiency.

The total overhead time, T_{OH} includes the CSC, and is defined by

$$T_{OH} = (120 + 80N)_{CSC} + (141N)_{MSG}$$

$$T_{OH} = 120 + 221N$$

The total message time (or bits) is

$$T_M = NM$$

where N is the number of earth stations.

Frame efficiency is simply

$$F_e = \frac{NM}{T_{OH} + NM} \times 100\%$$

SS-TDMA/Fixed Beam Channelization

The effective transmission rate for this TDMA system will be calculated on the basis of a fully loaded system, i.e., all earth stations are active.* For any earth station in a given TDMA network, the effective rate for fixed time assignment is as follows:

* It follows that the effective rate (the throughput) of any one earth station in the TDMA network can be improved if all earth stations are not simultaneously active and that statistical time assignment is employed.

$R_{eff} = F_e R_B/N$ for a burst rate R_B, frame efficiency F_e and N earth stations all carrying the same amount of traffic.

Table 4.1-25 and Figure 4.1-26 illustrate the tradeoffs that are available for TDMA systems such as those described here. Values of the effective data rate in the table are normalized to a burst rate of 10 Mbps parametric in message block length and the number of active earth stations in the net. Figure 4.1-20 describes the amount of data that can readily be transferred between TDMA earth stations operating with fixed time assignment.

By using the previously derived data, it is possible to determine the number of FDMA carriers required for this channelized TDMA payload. Since the previous data are based on a peak capacity of 5 Gbps, so will the satellite channel parameters. This is accomplished in Table 4.1-26, where we derive the number of satellite channels required for each 5 Gbps of traffic capacity, on the basis of burst rates of 20 Mbps, 100 Mpbs and 256 Mbps. Extending these channel loadings to other peak data rates is accomplished in Table 4.1-27. In this table, we also assign spare channelizing units (on the basis of 10% sparing). Because the burst rates are moderate to high, a large number of earth terminals are serviced in the time domain. Therefore, the SS-TDMA/Fixed Beam satellite is not channelized to as high a degree as the SS-FDMA satellite payload. Utilization of lower burst rates results in fewer earth stations serviced per carrier frequency and increases the demand for carrier frequencies.

SS-TDMA/Fixed Beam Switch Characteristics and Implementation

The channelization structure of this payload requires the switch to transfer data having an instantaneous bandwidth of up to a nominal 166 MHz. Switching should also occur in a small portion of the guard time. In a switch matrix study performed by General Electric for the 1987 time frame, the characteristics of an I.F. switch and a baseband switch were compared (see Table 4.1-28). The baseband switch operates to frequencies of about 120 MHz now and is projected to operate to frequencies of about 700 MHz by 1987. Therefore, the "baseband" switch approach, using CMOS/SOS LSI is directly useable at low values of the intermediate frequency and can, with reasonable confidence be employed at IF center frequencies of 300 to 400 MHz.

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Table 4.1-25. Effective Transmissions Rate for TDMA with 10 Mbps Burst Rate

Number of Earth Stations	Effective Transmission Rate (Mbps) for Data Message Bit Lengths of:						
	800	1000	1200	1600	2000	4000	8000
1	7.01	7.46	7.79	8.24	8.54	9.2	9.59
2	3.70	3.91	4.05	4.25	4.38	4.67	4.83
5	1.53	1.61	1.66	1.73	1.78	1.9	1.94
10	0.774	0.811	0.84	0.87	0.90	0.94	0.97
20	0.389	0.408	0.42	0.44	0.45	0.47	0.486
50	0.160	0.163	0.17	0.18	0.18	0.19	0.195
100	0.078	0.082	0.084	0.088	0.09	0.095	0.0973

For other burst rates, multiply by new burst rate by Mbps/10

* Per Carrier with 10 Mbps

Effective Transmission Rate, $R_{eff} = \frac{\text{Data Time/User in 1 Frame}}{\text{Total Time in 1 Frame} \times N} \times \text{Burst Rate}$

Table 4.1-26. Satellite Loading for a TDMA/FDMA System with Fixed Time Assignment and 5 Gbps Peak Capacity

System Parameter	Satellite Loading Characteristics			
	1 T-1	4 T-1	10 T-1	
Rate (Mbps)	1.544	6.176	15.44	
Bandwidth (Mhz)	1.0	4.01	10.04	
Number of Earth Stations	968	473	162	
Effective Rate (Mbps)	0.5	5.8	11.0*	
Number of Earth Stations Per Carrier	32	14	7	19
Burst Rate (Mbps)	20	100	100	256
Burst Bandwidth (MHz)	13.0	65.0	65.0	166.4
Number of Carriers (Channels) Required on the Spacecraft	31	34.0	23.0	9.0
1/2 Bit Offset QPSK *Average of 3 Bit Rates				

Nominal Bandwidth/Beam, 46 Beams and a 1/4 Frequency Use Factor

$$\frac{(31 \times 13\ \text{MHz}) + (34 \times 65\ \text{MHz}) + (9 \times 166.4\ \text{MHz})}{46/4} = 357.4\ \text{MHz/Beam}$$

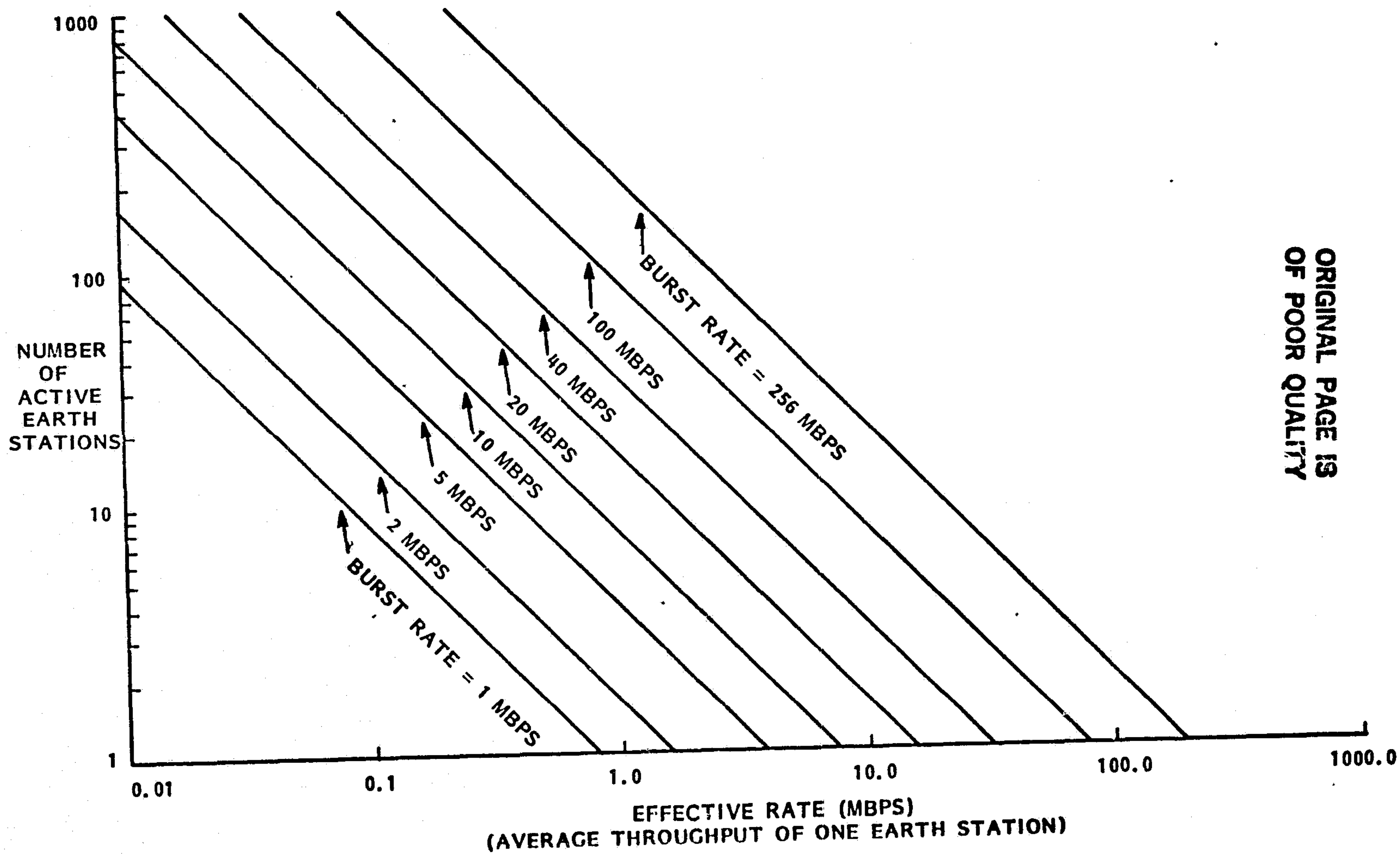

Figure 4.1-20. TDMA Burst Rate Required, with Fixed Time Assignment

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Table 4.1-27. SS-TDMA/FDMA Channel Characteristics

Rate (Mbps)	20 Mbps Burst Channels			100 Mbps Burst Channels			256 Mbps Burst Channels		
	Required	Spares	Total	Required	Spares	Total	Required	Spares	Total
500	4	1	5	4	1	5	1	1	2
1,000	7	1	8	7	1	8	2	1	3
2,000	13	2	15	14	2	16	4	1	5
5,000	31	4	35	34	4	38	9	1	10
10,000	62	7	69	68	7	75	18	2	20
15,000	93	10	103	102	11	113	27	3	30
20,000	124	13	137	136	14	150	36	4	40
40,000	248	25	273	272	28	300	72	8	80

Table 4.1-28. Comparison of IF & Baseband Switches for the 1987 Time Frame

PARAMETER	LARGE IF SWITCH	BASEBAND SWITCH
Matrix size	96 x 96	Same
Connectivity	Any of the inputs to any of the outputs. One for one.	Same
Reconfiguration rate	< 2 microseconds	Same
Switching time	< 10 nanoseconds	< 10 nanoseconds
Computer interface	61 lines	Same
Electrical performance		
Input signal level	-5 ± 5 dBm	-6 ± dBm
Frequency spectrum	8 ± 0.25 GHz	25 to 500 MHz
Flatness	± 1 dB	± 1 dB
Phase linearity	± 5° max.	± 5° max.
Isolation	≥ 40 dB all inputs Equal signal strength	≥ 42 dB all inputs Equal signalstrength
Insertion loss	30 dB max.	32 dB max.
Noise	> 35 dB below output signal level	> 35 dB below output signal level
Intermodulation (3rd order)	- 30 dB Two equal tones	- 34 dB Two equal tones
Impedance (input/output)	50 ohms	Same
VSWR (input/output)	1.2:1	Same
Power consumption	129.3 watts (1.4×10^{-2} W/XPT)	63 watts(6.84×10^{-3} W/crosspoint)
Reliability (10 year mission)	0.76867	0.91019
Mechanical		
Size	12 x 12 x 2 in.	10.5x10.5x3.5 in.
Weight	11.5 lbs (1.25×10^{-3} lbs per crosspoint)	12.7 lbs (1.38×10^{-3} lbs/crosspoint)
Scaleability beyond 96 x 96	Feasible with degraded performance	Same
Growth to larger bandwidth	Same as above	Same
Operating temperature	-10°C to +50°C	Same

However, the 166 MHz bandwidth results in a fractional bandwidth of 55.5% to 41.6% in the 300 MHz to 400 MHz region respectively. Therefore, the IF switch implementation is a relatively low risk approach for the 256 MHz burst rate. Channels having lower burst rates can employ the CMOS/SOS baseband switch, resulting in reductions of power and weight on a per channel basis.

For the switch matrices alone, the weight and power requirements are as given in Table 4.1-29.

As with the SS-FDMA system (Section 4.1.1), the channelizing units will be integrated with the switch matrix and the switch matrix will be partitioned by burst rate. The combination of an uplink channelization unit and a downlink channelizing unit weighs 0.125 pounds and consumes 540 mW per channel. Table 4.1-30 contains both the trade-off between the crossbar and Clos three-stage non-blocking switch as well as the power and weight requirements for the integrated channelizing unit and switch assembly. Values from this table will be selected for purposes of estimating satellite payload power and weight. The shaded areas represent approaches that have been rejected.

Total weight and power at any aggregate data rate is the sum of the weights and powers for each switch section, at that aggregate rate.

Payload Diagram, Weight and Power Summaries

A payload diagram for the SS-TDMA/Fixed Beam system is shown in Figure 4.1-21, channelized for the New York beam of a 46 beam system. For a 5 Gbps aggregate rate, the New York rate is 773 Mbps.

Channelizing units are scaled by the ratio of 773 for each burst rate, using Table 4.1-30, and the satellite is merely expanded to accommodate the other beams, which are not shown. Each transmit beam has its own TWTA, which is operated in a normal FDMA fashion with output back-off to maintain linear operation. Because of the relatively high burst rates, the satellite is not channelized to the extent that the SS-FDMA satellite is. For the New York beam, we have 14 channels in the TDMA system as compared to 128 channels for SS-FDMA for the same aggregate bit rate.

Table 4.1-29. Weight and Power Requirements for SS-TDMA/FDMA Switch

Burst Rate (Mbps)	Type of Switch	Weight and Power for Each Switch Point Pounds	Watts
256	I.F.	1.25×10^{-3}	1.4×10^{-2}
100	Baseband	1.38×10^{-3}	6.48×10^{-3}
20	Baseband	1.38×10^{-3}	6.84×10^{-3}

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Table 4.1-30. Switch and Switch Plus Integrated Channelizing Unit Characteristics, SS-TDMA/FDMA Payload

Aggregate Rate (Mbps)	256 Mbps Burst Rate Channels	No. of Switch Points: Cross Bar +20% Spares	No. of Switch Points: Clos, 3 Stg n = 8	Switch: Weight (Pounds)	Switch: Power (Watts)	Switch with Integrated Channelizing Units: Weight (lbs)	Switch with Integrated Channelizing Units: Power (watts)
500	2	5	75	1 (min)	0.08	1.3	1.2
1000	3	11	93	1	0.15	1.4	1.8
2000	5	30	126	1	0.4	1.6	3.1
5000	10	120	158	1	1.7	2.3	7.5
10000	20	480	694	1	6.7	3.5	17.5
15000	30	1080	1111	1.4	15.1	5.2	31.3
20000	40	1920	1575	2.0	22.1	7.0	43.7
40000	80	7680	3900	4.9	54.6	14.9	97.8
	100 Mbps Burst Rate Channels						
500	5	30	156	1 (min)	0.2	1.6	2.9
1000	8	77	255	1	0.53	2.0	4.9
2000	16	307	540	1	2.1	3.0	10.7
5000	38	1733	1479	2.0	10.1	6.75	30.62
10000	150	6750	3569	4.9	24.4	14.3	64.9
15000	113	15323	6383	8.8	43.7	22.9	104.72
20000	150	27000	9774	13.5	66.9	32.3	147.9
40000	300	108000	30094	41.5	205.8	79.0	367.8
	20 Mbps Burst Rate Channels*						
500	5	30	156	1 (min)	0.2	1.6	2.9
1000	8	27	255	1	0.53	2.0	4.9
2000	15	270	503	1	1.9	2.9	10.0
5000	35	1470	1338	1.8	9.2	6.2	28.1
10000	69	5713	3186	4.4	21.8	13.03	59.1
15000	103	12731	5577	7.7	38.2	20.6	93.8
20000	137	22523	8509	11.7	58.2	28.8	132.2
40000	273	89435	25658	35.4	175.5	69.5	322.9

* Includes spares

The total switch weight and power at any aggregate data rate is the sum of the partitioned sections (e.g., at 5000 Mbps, the total weight, including channelizing units is 2.3 (256 Mbps) + 6.75 (100 Mbps) + 6.2 (20 Mbps) = 15.25 pounds)

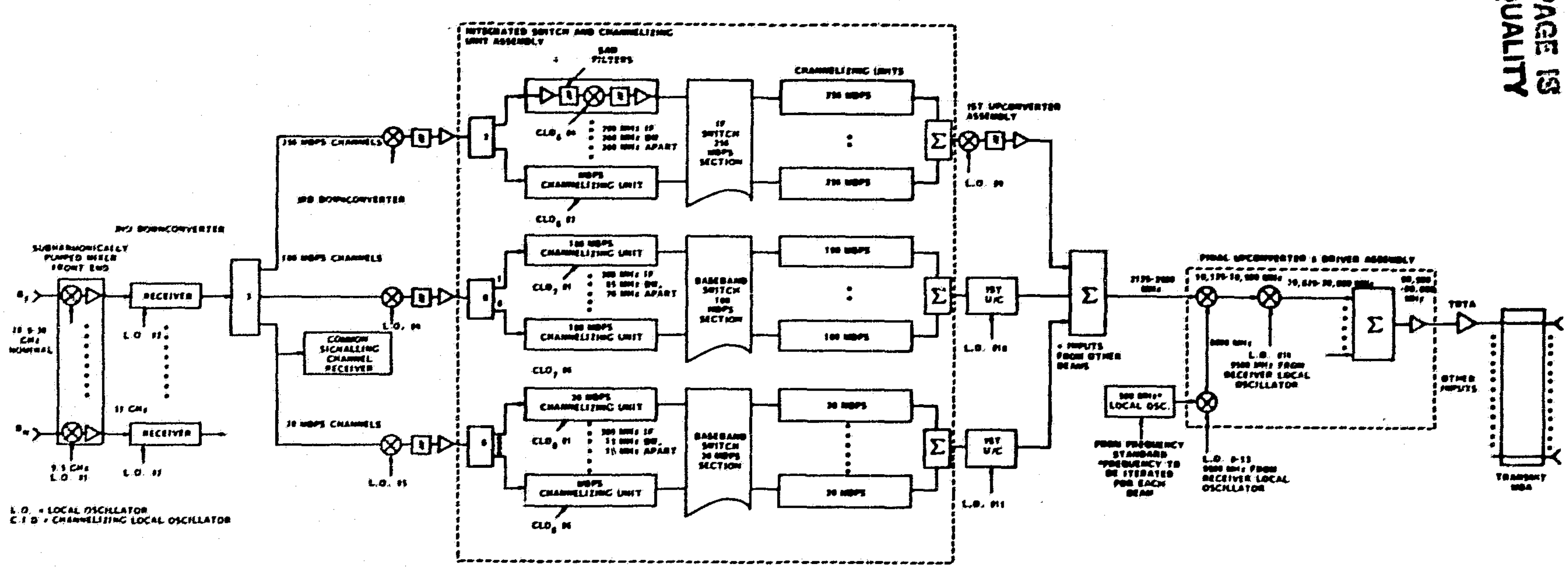

Figure 4.1-21. Functional Block Diagram for SS-TDMA/FDMA Payload, Configured for the New York Beam Aggregate Rate = 5 Gbps, 46 Beams (New York Rate = 773 Mbps)

Weight and power requirements for this SS-TDMA/Fixed Beam payload are described in the following and are summarized in Table 4.1-31.

1. Receive Antenna - Identical to SS-FDMA's, Section 4.1.1.
2. Receiver and Second Downconverter - Identical to SS-FDMA, Section 4.1.1.
3. Third Downconverter - Identical to SS-FDMA, Section 4.1.1.
4. Local Oscillator Assemblies - See Table 4.1-32.
5. Integrated Switch and Channelizing Assembly - See Table 4.1-30
6. Common Signalling Channel Equipment - Four pounds and four watts.
7. First Upconverter Assembly - Identical to SS-FDMA, Section 4.1.1.
8. Final Upconverter and Driver Assembly - Identical to SS-FDMA, Section 4.1.1.
9. TWTA - Weight = 0.106 W_{RF} + 6 pounds
   Power = 2.5 W_{RF} (6 dB Backoff assumed)
10. Transmitter Output Assemblies - Identical to SS-FDMA, at 1.68 pounds.
11. Transmit Antenna - Identical to SS-FDMA, Section 4.1.1.

Equations are summarized in Table 4.1-31. Specific input parameters for the switch matrix are summarized in Table 4.1-33 and the EIRP parameters are in Table 4.1-34. Summaries of the payload weight and power for the SS-TDMA/Fixed Beam payloads are contained in Figures 4.1-22 and 4.1-23, respectively.

4.1.3 HYBRID FDMA UPLINK/TDMA DOWNLINK SYSTEM CONCEPT

In this system concept, payload is shown in Figure 4.1-24, the uplink Single Channel Per Carrier (SCPC) digital data streams access the satellite transponder by means of FDMA to avoid the burden of high-speed burst operation, which would require high-speed modems and a large HPA. Access through the satellite beams is determined by the carrier frequency, similar to SS-FDMA. However, since the data is reformatted into a TDM downlink stream, on-board demodulation, processing and remodulation is required. Also, in contrast to SS-FDMA, the earth station G/T and the satellite EIRP must support the high burst rate on the downlink.

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Table 4.1-31. Summary of SS-TDMA/FDMA Weight and Power Equations

Item	Quantity	Total Weight (Pounds)	Total Power
Receive Antenna	1	$0.87\ N_F + 0.8A_R + 3.37\ D_R + 15$	$0.75\ N_B$
2nd D/C (Receiver)	1/Beam	$0.68\ N_B$	$0.45\ N_B$
3rd D/C	3/Beam	$0.42\ N_B$	$0.9\ N_B$
Integrated Switch & Channelizing Units	See Table 4.1-30	See Table 4.1-30	See Table 4.1-30
Common Signalling Equipment	1	4	4
Local Oscillators	See Table 4.1-32	$13.6 + 2.86\ N_B/13 + 0.412\ N_B + 0.206\ N_{256} + 0.206\ N_{100} + 0.206\ N_{20}$	$38 + 1.8\ N_B/13 + 0.4\ N_B + 0.2\ N_{256} + 0.2\ N_{100} + 0.2\ N_{20}$
1st Upconverter Assembly	3/Beam	$0.42\ N_B$	$0.9\ N_B$
Final Upconverter and Driver Assembly	1/Beam	$0.98\ N_B$	$0.7\ N_B$
TWTA	1/Beam	$0.106\ W_{RF} + 6$	$2.5\ W_{RF}$
Tranmsmitter Output	1/Beam	$1.68\ N_B$	-
Transmit Antenna	1	$0.99\ N_F + 0.8\ A_R + 3.37\ D_R + 15$	-
		SUBTOTAL	
		Harness (2%) Brackets, Boxes (1%)	
		Low Voltage Power Supply (1%) Contingency (10%)	
		TOTAL	

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Table 4.1-32. Local Oscillator Requirements, SS-TDMA/FDMA Payload

Item	Quantity Required Active	Quantity Required Redundant	Unit Weight (Pounds)	Unit Power (Watts)	Total Weight (Pounds)	Power (Watts)
Frequency Standard	1	1	0.8	1.5	1.6	1.5
9.5 Ghz Local Oscillator, L.O. #1 & L.O. #13	1	1	1.25	11.0	2.5	11.0
9.5 GHz Amplifier	1	1	0.1	0.2	$0.2\ N_B/13$	$0.2N_B/13$
9.5 GHz Power Divider and coax	1	--	0.106	--	$0.106\ N_B/13$	--
8.5 GHz Local Oscillator, L.O. #2 & L.O. #13	1	1	1.25	11.0	2.5	11.0
8.5 GHz Amplifiers	2	2	0.1	0.2	$0.4N_B/13$	$0.4N_B/13$
8.5 GHz Power Divider and coax	2	--	0.106	--	$0.212N_B/13$	--
1955 MHz, L.O. #3 and L.O. #9	1	1	0.5	3.0	1.0	3.0
1955 MHz Amplifier	1	1	0.1	0.2	$0.2N_B/13$	$0.2N_B/13$
Power Divider and coax	2	--	0.106	--	$0.212N_B/13$	--
L-Band L.O. #4, 5, 10, 11	2	2	0.5	3.0	2.0	6.0
1000 MHz Amplifier	4	4	0.1	0.2	$0.8N_B/13$	$0.8N_B/13$
Power divider and Coax	4	--	0.106	--	$0.424N_B/13$	--
500 MHz Oscillator, L.O. #12	1	1	0.5	3.0	1.0	3.0
500 MHz Amplifier	1	1	0.1	0.2	$0.2N_B/13$	$0.2N_B/13$
Power Divider and Coax	1	--	0.106	-	$0.106N_R/13$	--
UHF Comb Generator, L.O. #6, 260 MHz Spacing	1	1	0.3	0.5	0.6	0.5
UHF Amplifiers	1	1	0.1	0.2	$0.1\ N_B$	$0.2N_B$
Power Divider and coax	1	--	0.106	--	$0.106\ N_B$	
UHF Comb Generator, L.O.#7 70 MHz Spacing	1	1	0.3	0.5	0.6	0.5
UHF Amplifier	1	1	0.1	0.2	$0.1N_B$	$0.2N_B$
Power Divider and coax	1	--	0.106	--	$0.106N_B$	--
UHF Comb Generator L.O. #8 15 MHz spacing	1	1	0.3	0.5	0.6	0.5
UHF Amplifier	1	1	0.3	0.5	0.6	0.5
Power Divider and Coax	1	1	0.3	0.5	0.6	0.5
UHF Amplifiers, 256 Mbps Channels	1	1	0.1	0.2	$0.1N_{256}$	$0.2N_{256}$
UHF Amplifiers, 100 Channels	1	1	0.1	0.2	$0.1N_{100}$	$0.2N_{100}$
UHF Amplifiers, 20 Mbps channels	1	1	0.1	0.2	$0.1N_{20}$	$0.2N_{20}$
Power Dividers & Coax 256 Mbps Channels	1	--	0.106	--	$0.106N_{256}$	--
Power Dividers & Coax 100 Mbps Channels	1	--	0.106	--	$0.106\ N_{100}$	--
Power Dividers & Coax 20 Mbps channels	1	-	0.106	--	$0.106\ N_{20}$	--

Weight L.O. = $13.6 + 2.86\ N_B/13 + 0.412\ N_B + 0.206N_{256} + 0.206\ N_{100} + 0.206N_{20}$ Pounds

Power L.O. = $38 + 1.8\ N_B/13 + 0.4N_B + 0.2N_{256} + 0.2N_{100} + 0.2N_{2o}$

Table 4.1-33. Summary of Channels And Switch Matrix Data

DATA RATE Mbps	TABLE 4-3 EXCERPT N_{cu} for computing WEIGHT	POWER	TABLE 5-3 SWITCH MATRIX WEIGHT	POWER
500	12	9	4.5	7.0
1000	19	16	5.4	11.6
2000	36	31	7.5	23.8
5000	83	74	15.25	65.8
10,000	164	148	30.83	141.5
15,000	246	222	48.7	229.8
20,000	327	296	68.1	323.8
40,000	653	592	163.4	788.5

TABLE 4.1-34. EIRP FOR TDMA WITH 1 METER EARTH STATION ANTENNA

No Diversity	99.5%	Availability 99.9%	99.95%
Overall Average	49.50 dBW	69.16 dBW	94.09 dBW
C, B, F Rain	46.7	46.7	48.8
D	47.7	52.3	60.3
E	55.3	78.3	103.3
With Diversity			
Overall Average	49.73		
C, B, F Rain	47.1		
D	47.6		
E	55.7		

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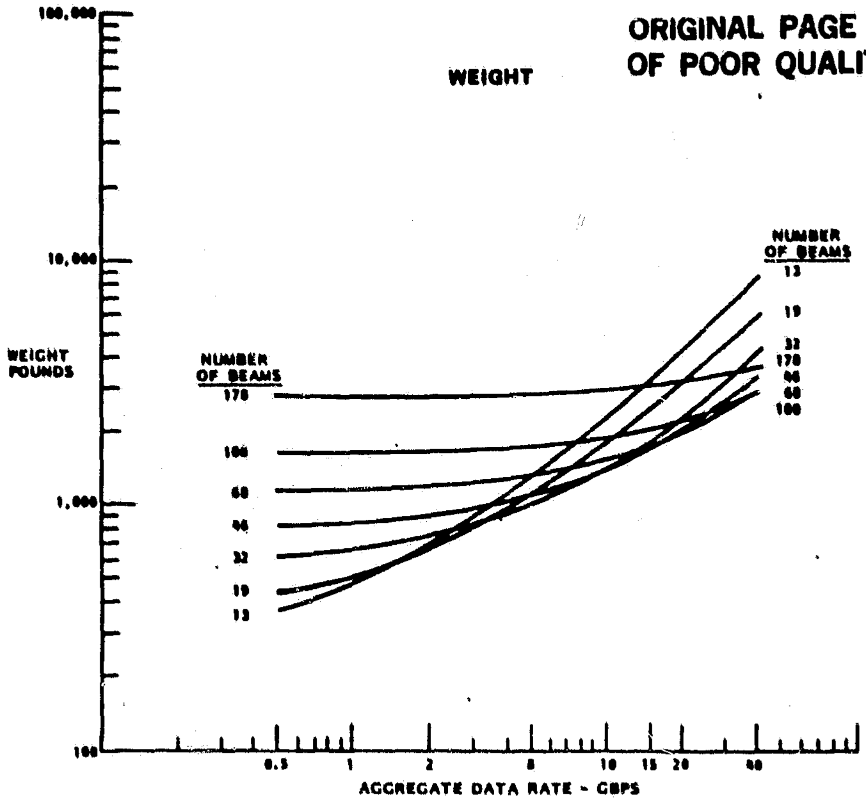

Figure 4.1-22. Weight of SS-TDMA/Fixed Beam Payload

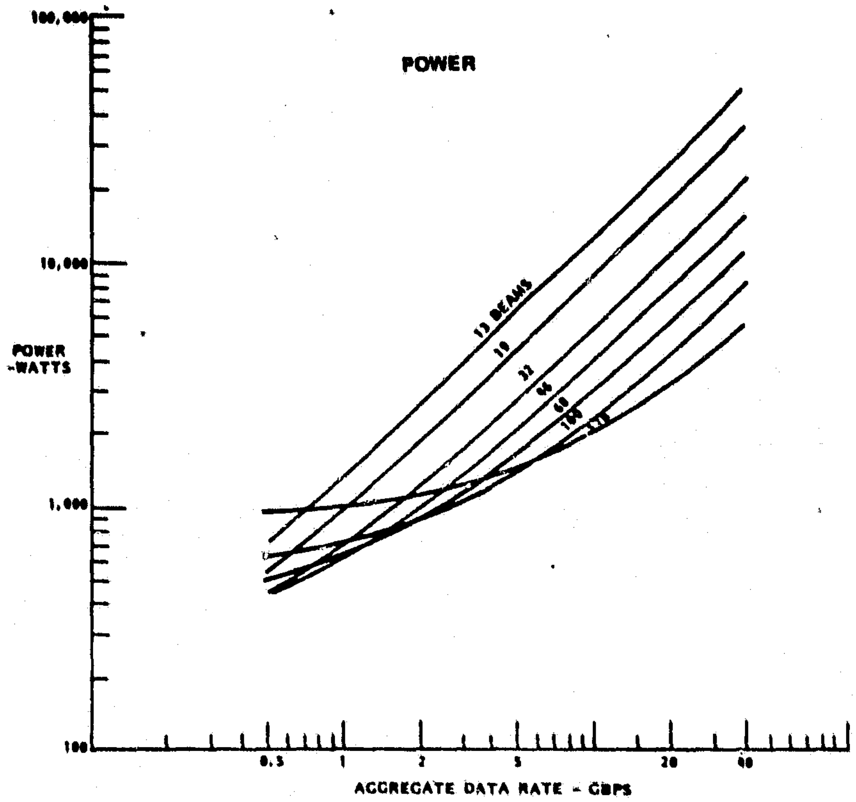

Figure 4.1-23. SS-TDMA/Fixed Beam Subsystem Payload Power

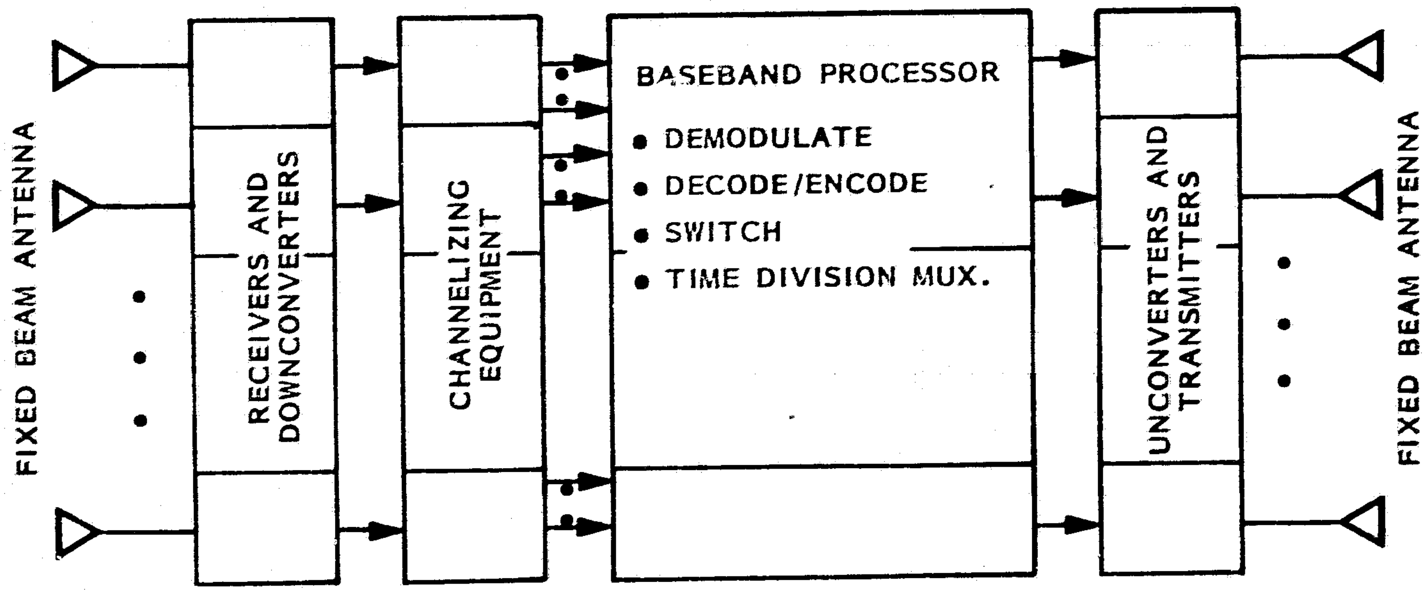

Figure 4.1-24. HYBRID System, FDMA Up and TDMA Down, Concept

The HYBRID system concept uses fixed beam receive and transmit antennas. Each beam has a low noise preamplifier, receiver and frequency division demultiplexing equipment (channelizing units), followed by on-board demodulation. The baseband processor provides convolutional decoders where required for the uplink bit streams and reformats the data for the downlink.

Minimizing the burden on the earth station requires maximizing the spacecraft EIRP and making the downlink efficient by reducing overhead and constraining the transmission rate. Rate constraints can be developed by using frequency division multiplex (FDM) to support multiple downlink TDM groups within each beam coverage area. Each downlink is time division multiplex (TDM), rather than TDMA, and the downlinks run at constant data rates and carrier frequencies with only one frequency assigned to each downlink, thereby enabling the use of a coherent demodulator at the earth station and eliminating the need for burst-to-burst acquisition as required in a pure TDMA system. In addition, the final high power amplifiers in the satellite can operate in a saturated mode, leading to the most efficient use of the downlink power, if only a few carriers are used in a frequency division multiplexed TDM downlinks.

FDMA Uplink Channelization

Traffic modelling indicates that an appropriate balance between spacecraft complexity and satisfaction of user needs occurs when the channel capacities are quantized into three groups - 40 Mbps, 6 Mbps and 1.5 Mbps. Compatibility with standard T1 channelizing equipment will be attained by setting the latter two rates 6.176 Mbps and 1.544 Mbps respectively.

A traffic analysis for a 46 beam system and an aggregate data rate of 5 Gbps are shown in Table 4.1-35. Of interest is the fact that a large number of users require low data rate service and that the vast majority of these can be preassigned, thereby reducing the weight and power requirements when an IF switch is used. However, for an FDMA uplink with a TDMA downlink, the advantages of preassignment are far more subtle than on a pure FDMA system. In fact, it would appear that the principal advantage lies in being able to reduce the activities of the Resource Controller, Routing Processor and Memory Controller. All other elements must be expanded to accommodate the total number of channels.

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Table 4.1-35. FDMA Channelizing Plan Based on Traffic Analysis*

Rate (Mbps)	40 Mbps Channels			6.176 Mbps (4 T-1 Ch)			1.544 Mbps Channels			Sub Total Pre-Assigned	Sub Total Switched	Sub Total Spares	Total Channels
	Pre-Assign	Switch	Spares	Pre-Assign	Switch	Spares	Pre-Assign	Switch	Spares				
500	0	0	0	0	0	0	2138	46	218	2138	46	218	2402
1000	0	0	0	16	8	3	2148	46	218	2164	54	221	2439
2000	0	0	0	86	20	1	2148	46	218	2234	66	229	2529
5000	12	4	2	324	60	38	2148	109	226	2484	173	266	2923
10000	55	24	8	719	97	82	1919	151	207	2693	272	297	3262
15000	98	47	14	1114	135	125	1691	194	189	2903	376	328	3607
20000	200	80	28	1114	135	125	1691	194	189	3005	409	342	3756
40000	500	240	74	1114	135	125	1691	194	189	3305	569	388	4262

All Spares are switched. For SS-FDMA Uplink & Downlink, the number of channelizing units is doubled.

* Private communication, 12 March 1982

Because of the large number of channels, the use of Large Scale Integration (LSI) will need to be accelerated to permit building T1 modems and codecs on a chip.

Major functional codec elements are currently being implemented in CMOS and TRW is designing some critical elements of a Viterbi Decoder for their Phase I VHSIC Development Contract. A T1 modem chip set and a codec chip set appear to be realistic expectations by the 1985/1987 time frame.

The payload diagram of Figure 4.1-25 demonstrates an architecture very much like that of a fixed beam SS-FDMA system using separate receiving and transmitting antennas with independent beams. Separate, fully redundant receivers and downconverters are utilized on each beam, being placed as close as possible to the feed horns to preserve the satellite G/T.

The output of the 1st downconverters is power divided, undergoes further downconversion and is then channelized into 40 Mbps, 6.176 Mbps, and 1.544 Mbps channels (3 levels of bandwidth quantization). The IF switch has been partitioned in the same manner as the bandwidth and has been defined in terms of CMOS/SOS Technology available in 1987. Aiding in the reduction of switch complexity is a high level of preassignment. Channelization units are not redundant, however, 10% spares are available and all spares are switched.

In this FDMA plan, all channelizing units have a 70 MHz IF output; utilization of this low frequency IF allows the use of Surface Acoustic Wave (SAW) filters and other monolithic as well as discrete components to be integrated on a single substrates and thereby achieve the low weight and power requirements dictated by the quantity of channelizing units required for this payload. Weight and power requirements for the 70 MHz channelizing units are derived later.

Discussion of Alternative Processor IF Interface

A 70 MHz IF has been chosen for the final downconversion at the processor interface. This frequency is convenient to implement and RF circuits at 70 MHz are power efficient. However, this choice of frequencies is not convenient insofar as the current Motorola Baseband Processor development program is concerned. The Motorola Baseband Processor is being developed with an 8 GHz IF interface, which is convenient for the trunking and CPS data rates

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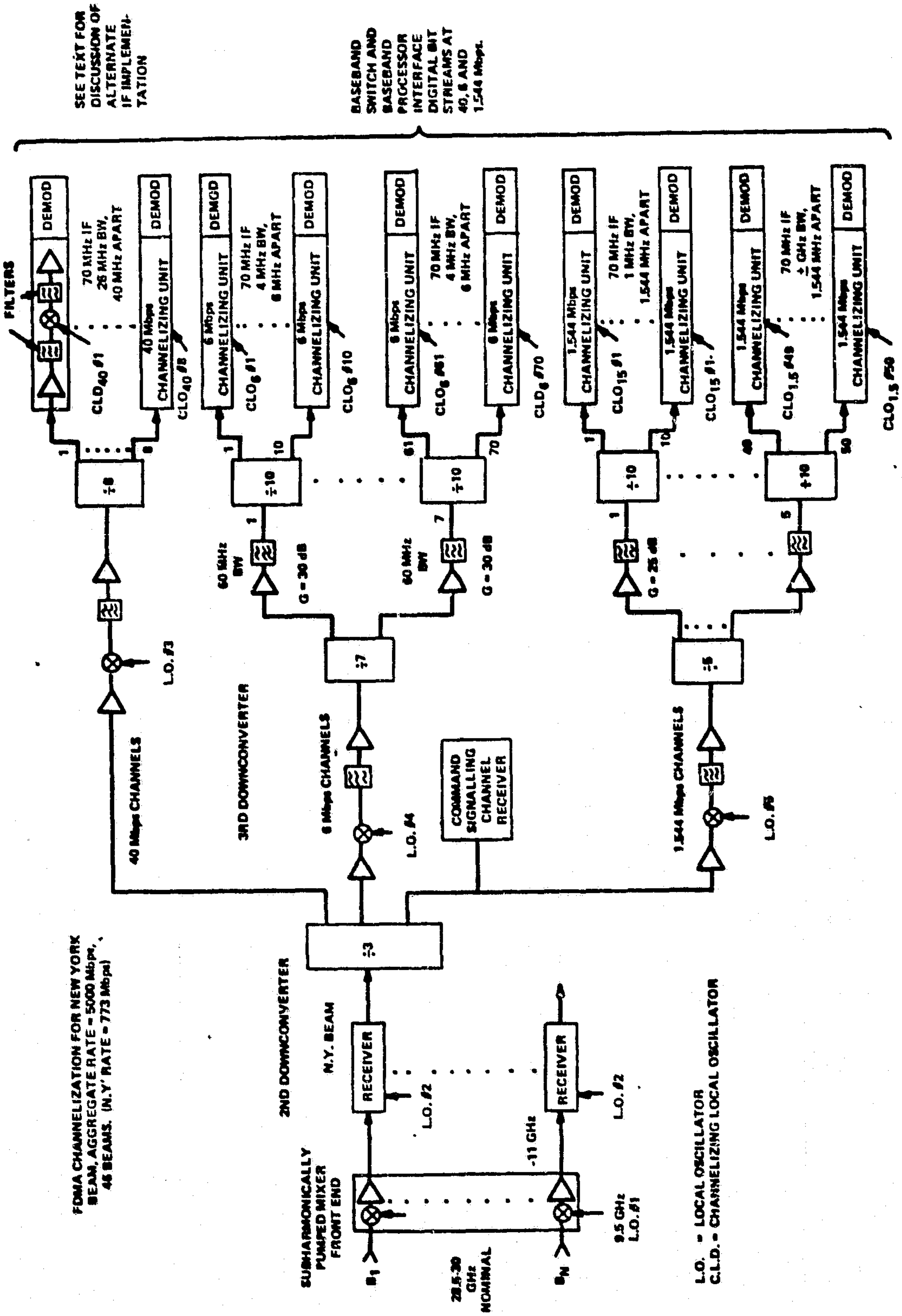

Figure 4.1-25. FDMA Channelization for New York Beam, 5 Gbps, 46 Beams (NY Rate = 773 Mbps)

envisioned by Motorola, viz, 27.5, 110 and 550 Mbps. High data rates such as these are not compatible with the large quantity of low speed (1.544 Mbps) channels that must be frequency demultiplexed. There is no known technique for economically filtering the T1 channels in a system operating at 8 GHz, which would give a filter bandwidth requirement of 0.019%, whereas SAW devices can be readily implemented at 70 MHz - 700 MHz with the required 2.2% bandwidth to 0.22% bandwidth, respectively.

QPSK Modem Design, Weight and Power

A QPSK Modem design has been extrapolated from an existing 8 GHz design to a thick-film hybrid design for flight. The demodulator and modulator together require 10 watts each and weighs 60 pounds for 96 modems. The QPSK demodulator represents 60% of the total parts count. Therefore each demodulator will be assumed to weigh 0.375 pounds (0.60 x 60 pounds/96 modems). Within the parts count, the demodulator consumes 72% of the power and the power per demodulator is therefore established as 7.2 watts at 8 GHz carrier. At 280 MHz the DC to RF conversion efficiency is approximately 80% as compared to about 30% at 8 GHz. Therefore, the required DC power for the new design is 3/8 of 7.2 watts, or 2.7 watts/channel.

A block diagram of the proven modem design is shown in Figure 4.1-26. Demodulation occurs in the following manner. The composite quadriphase spectrum is frequency multiplied by a factor of four (4). For a 70 MHz IF, the resulting signal is a carrier at 4 x 70 MHz = 280 MHz whose phase is independent of the modulation phase. A Carrier Recovery Tracking Phase Lock Loop (PLL) is then phase-locked to this signal. The phase-locked signal then constitutes the recovered carrier with the modulation removed. The recovered carrier is then applied to a synchronous demodulator together with the original modulated carrier. The demodulator outputs provide the in-phase (I) and the quadrature (Q) data outputs at baseband.

Weight and Power for an Integrated Channelizing Unit and QPSK Demodulator

Each channelizing unit and QPSK demodulator assembly weighs 0.274 pounds and consumes 1.0 Watt, as derived in Table 4.1-36. The quantity of channelizing units required is established in Table 4.1-35, parametric in the aggregate data rate.

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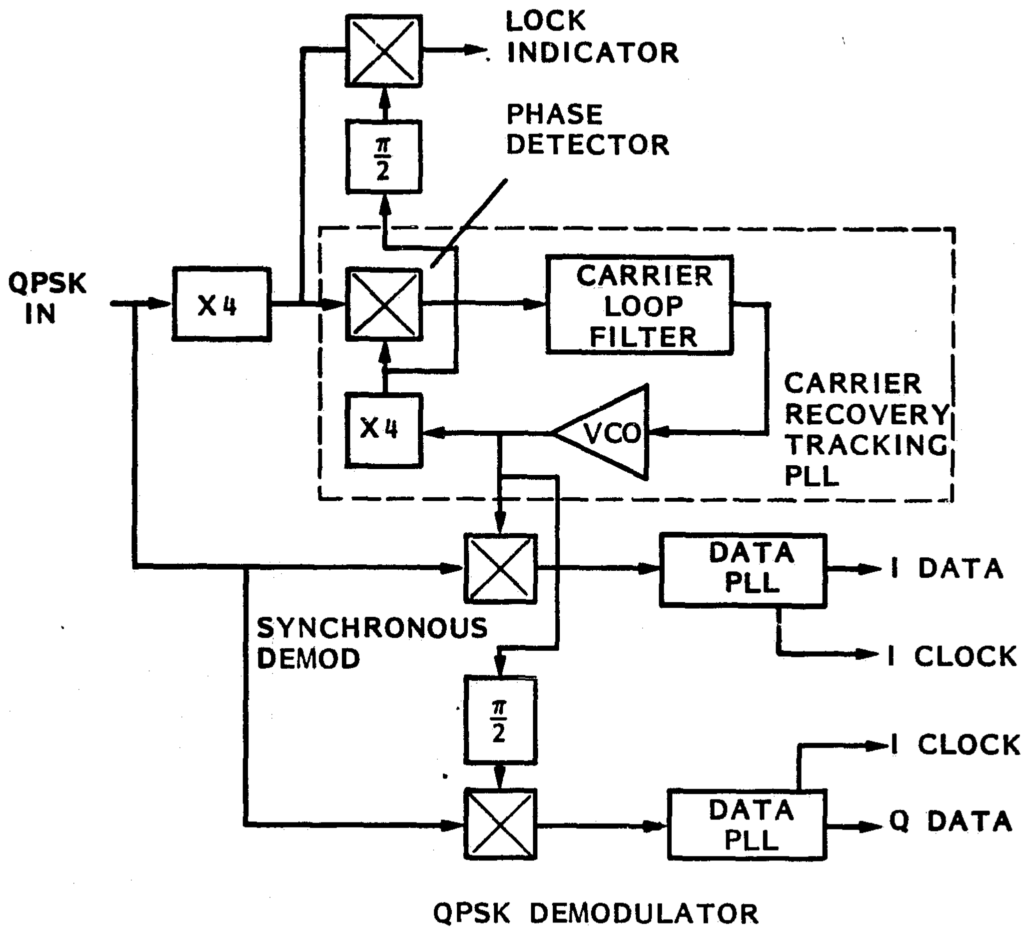

Figure 4.1-26. QPSK Demodulator Design

Table 4.1-36. Weight & Power Requirements For An Integrated Channelizing Unit And Demodulator Assembly

Item	Quantity Per Ch.	Unit Weight (Pounds)	Unit Power (Watts)	Total Weight (Pounds)	Total Power (Watts)
MMIC Channel UNIT*	1	0.094	0.270	0.094	0.270
QPSK Demod**	1	0.18	0.73	0.18	0.73
Totals for Integrated Assembly				0.274	1.00

*Parameters Defined in SS-FDMA Section, Section 4.1.1.

** Motorola 1987 Technology

Demodulator weight and power values are derived from the Motorola 1987* technology estimates for the 6 GHz Baseband Processor and are significantly less than those derived from the previously discussed existing design. The smaller values are used to develop the payload power and weight:

$$\text{Weight} = \frac{47 \text{ Pounds}}{263 \text{ Demods}} = 0.18 \text{ Pounds/Demod}$$

$$\text{Power} = \frac{191 \text{ Watts}}{263 \text{ Demods}} = 0.73 \text{ Watts/Demod}$$

Baseband Processor and Downlink Configuration

The processor input is a serial bit stream at either 40, 6, or 1.544 Mbps at each port, as shown in Figure 4.1-27.

An input buffer is required to momentarily store the data and to permit adjustment of the data flow to the processing rate. Each processor input port receives message data destined for a specific downlink, as arranged by the network controller. Routing to the proper input port depends on the baseband routing switch, current configuration and the frequency demultiplexing prior to the processing input. A dedicated Common Signalling Channel (CSC) is employed to achieve coordination and control.

The input buffer may be a part of the Time Division Multiplexer which is used to sample each input channel and to combine each of the channels into a composite output bit stream that represents the total data rate in each beam, as established by the aggregate data rate and the traffic models previously discussed in relation to the SS-FDMA System. Ideally, channelizing units and demodualtors should be integrated with the baseband processor to reduce the weight and labor related to a large number of coaxial connections.

Downlink control begins with time slot assignments made by the Resource Controller under the direction of the Network Control Center. The Resource Controller translates the time slot assignments into commands for the memory controller and the routing processor. Downlink bit streams are assembled by

* Motorola Inc., "30/20 GHz Communication System, Baseband Processor Subsystem", Task 1, Communication System Design Interim Report, November 18, 1980.

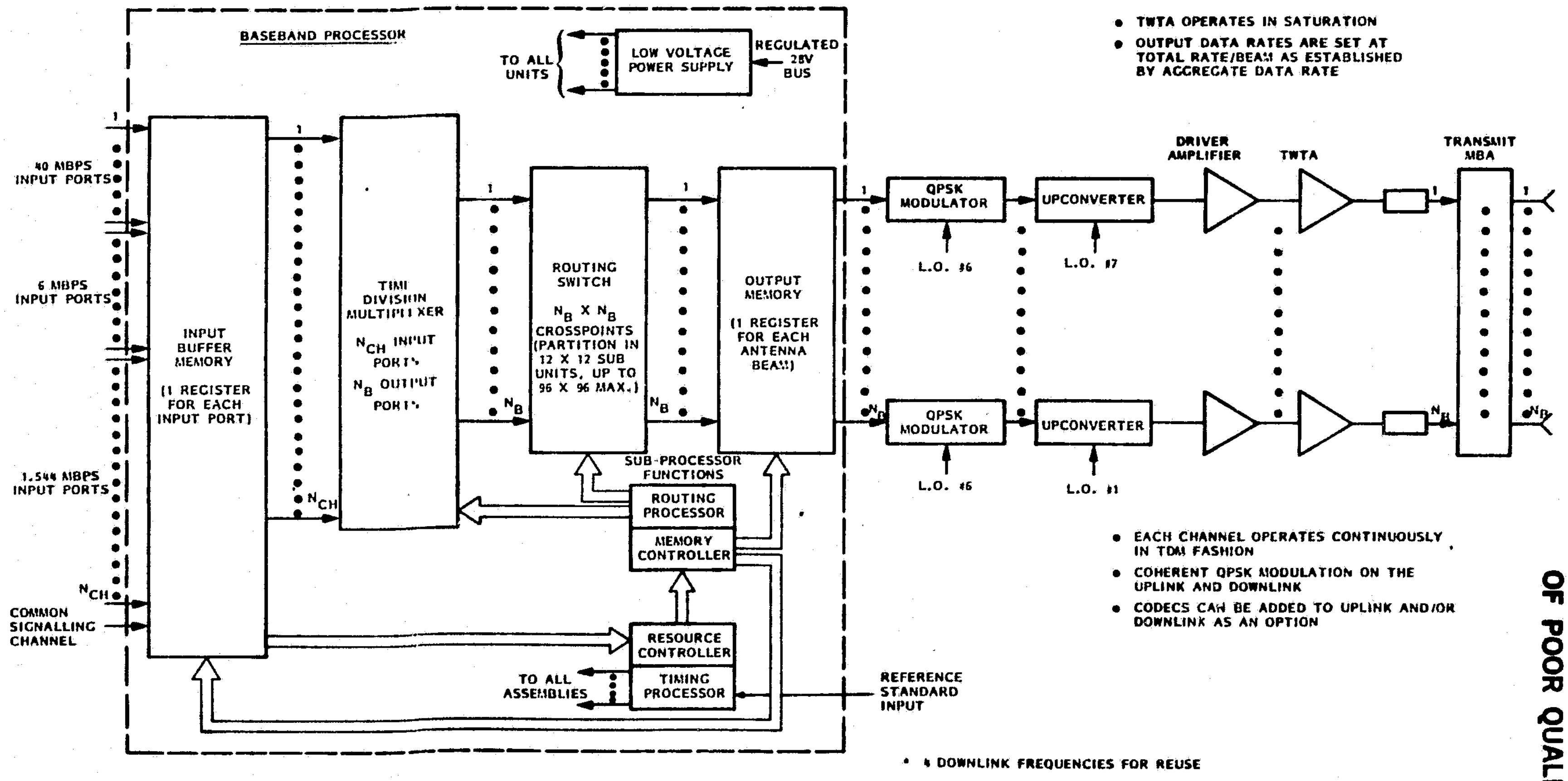

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Figure 4.1-27. FDMA to TDMA (TDM) Conversion and Downlink Configuration

the Time Division Multiplexer (TDM) and they are shifted to the Output Memory Registers (one per beam). The routing switch can be an integral part of the TDM, but is considered as a separate function here to assist in sizing the processor.

Weight and Power Requirements for the Baseband Processor

The estimated weight and power requirements of the processor are an extrapolation of Motorola data plus additional items needed to support this system. The Motorola system included the demodulators, codecs and modulators. Using the Motorola data for the 1987 technology and an aggregate rate of 3410 Mbps, and increasing the values by 10% to account for multiplexing overhead, we have

$$\text{Weight} = \frac{250 \text{ Pounds}}{3410 \text{ Mbps}} = 0.073 \text{ Pounds/Mbps}$$

$$\text{Power} = \frac{800 \text{ Watts}}{3410 \text{ Mbps}} = 0.025 \text{ Watts/Mbps}$$

Weight and Power Requirements for the Local Oscillator Assemblies, Receivers and Downconverters

Local Oscillator power requirements are derived in Table 4.1-37, parametric in data rate (DR) in Mbps and in the number of antenna beams (N_B). The local oscillator distribution plan is shown in Figure 4.1-28. A 70 MHz source is included for the transmitter and one of the K-Band Local Oscillators can be reused for the transmitter. For the FDMA Uplink/TDM Downlink, the total local oscillator weight and power requirements are as follows:

$$\text{Weight}_{LO} = [12.8 + 0.0438 \text{ DR} + 0.278 N_B] \text{ Pounds}$$

$$\text{Power}_{LO} = [35.8 + 0.0004 \text{ DR} + 0.196 N_B] \text{ Watts}$$

DR = Aggregate System Data Rate (capacity) in Mbps

N_B = Number of Beams

Downlink Modulator Design

The downlink modulator weight and power are as follows:

Weight = 0.3 pounds/antenna beam

Power = Carrier generation only

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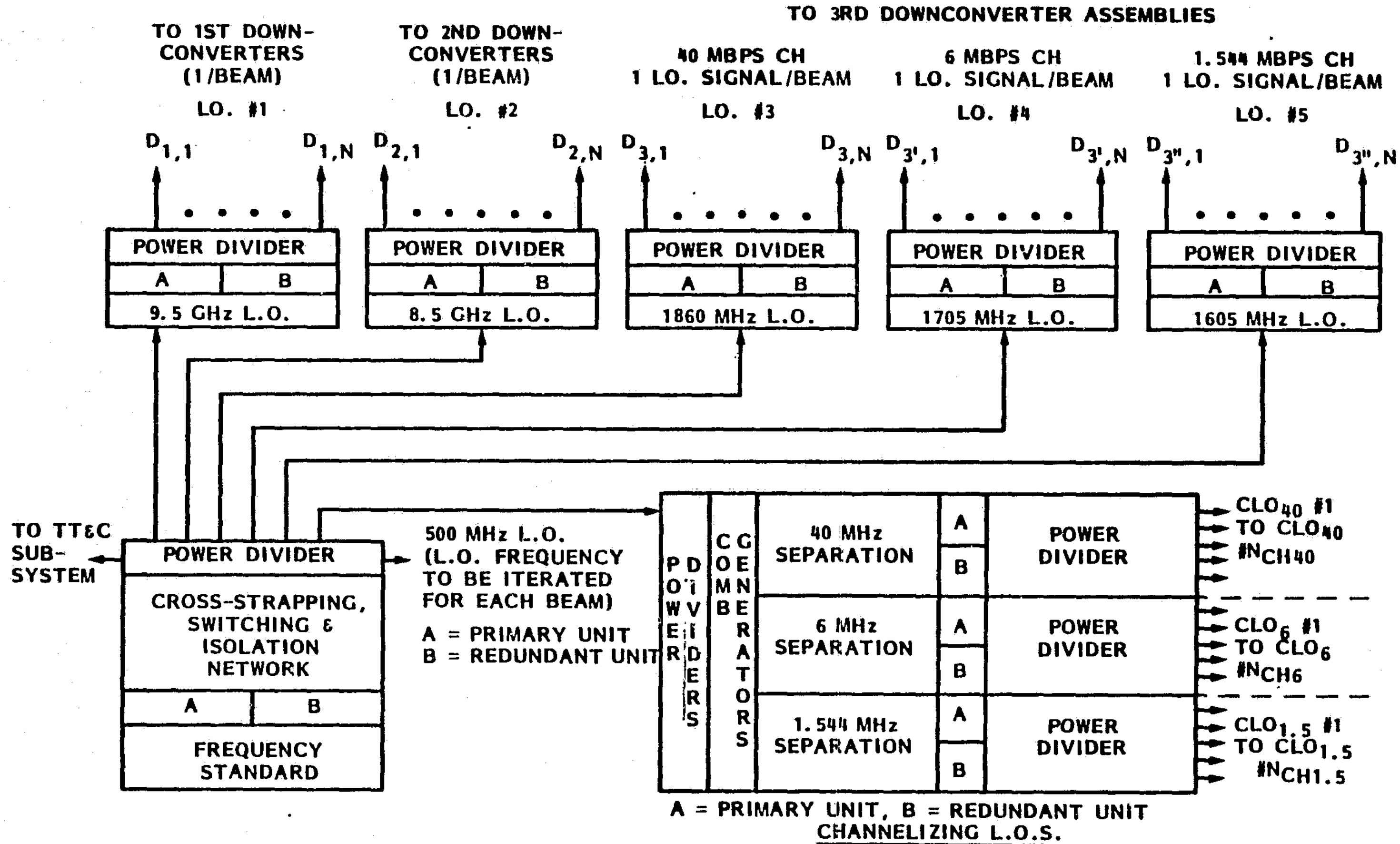

Figure 4.1-28. Functional Description of Local Oscillator Distribution Plan

Table 4.1-37. Local Oscillator Assemblies, Weight and Power Estimates

Item	Quantity Required	Unit Weight - Pounds	Total Weight* - Pounds	Power - Watts
Frequency Standard	2	0.8	1.6*	1.5
9.5 GHz Local Oscillator (1st downconverter)	2	1.25	2.5*	11.0
9.5 GHz Amplifier	2	0.1	$0.4N_B/13$*	$0.3N_B/13$
9.5 GHz Power Divider and Coax	1	---	$0.106N_B/13$	---
9.5 GHz Amplifier	1/beam	0.1	$0.2\ N_B$	$0.15N_B$
8.5 GHz Local Oscillator	2	1.25	2.5*	11.0
8.5 GHz Amplifiers	2	0.1	$0.4N_B/13$	$0.3N_B/13$
8.5 GHz Power Divider/Combiner	2	---	$0.106N_B/13$	---
70.0 MHz Source (Transmitter)	2	1.0	2.0	1.0
500 MHz Local Oscillator (Transmit)	2	0.3	0.6	0.5
L.O. For Third Downconverter	3	0.5	1.5	9.0
Amplifier for Third Downconverter	3	0.1	0.3	0.3
Comb Generator, 40 MHz spacing, 10 TAPS	2	0.3	0.6	0.5
Comb Generator, 6 MHz Spacing	2	0.3	0.6	0.5
Comb Generator, 1.544 MHz Spacing	2	0.3	0.6	0.5
Comb Generator amplifiers	0.026 DR	0.1	0.026 DR	0.0004 DR
Power Divider	0.026 DR	0.05	0.0013 DR	---
Coaxial Cable (feet)	0.165' DR	0.1	0.0165 DR	---

Weight = 12.8 + 0.0438 DR(Mbps) + 0.2 N_B + 1.012 $N_B/13$

Weight = 12.8 + 0.0438 DR(Mbps) + $0.278N_B$

Power = 35.8 + 0.0004 DR (Mbps) + 0.6 $N_B/13$ + 0.15 N_B

Power = 35.8 + 0.0004 DR (Mbps) + 0.196 $N_B/13$

N_B = Number of Beams; DR = Data Rate in Mbps

* Includes redundancy

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Weight and power of the QPSK modulator are virtually independent of the data rates and are directly proportional to the number of beams in a fixed beam configuration.

Driver, TWTA and Output Assemblies

The final upconverter and driver assembly is identical to that used for the SS-FDMA System.

$$\text{Weight} = 0.98\ N_B \text{ Pounds}$$

$$\text{Power} = 0.7\ N_B \text{ Watts}$$

EIRP requirements are derived in Table 4.1-38. It is assumed that the TWTA's operate in saturation. Each beam will have continuous downlink data streams that permit the use of relatively slow acquisition coherent demodulators in the earth station as contrasted to burst acquisition demodulators required by TDMA links.

TWTA weight is identical to all other configurations.

$$H_{TWTA} = (0.106\ W_{RF} + 6) \text{ Pounds}$$

$$P_{TWTA} = 2.5\ W_{RF} \text{ Watts (40\% efficiency)}$$

Economies of scale are expected to apply such that the above provides for shared redundancy. The transmitter output assemblies include redundancy switches and each one weighs 1.68 pounds.

Receive and Transmit Antenna Weight and Power Summaries

Weight summaries for the receive and transmit fixed beam MBA's are those given previously in Tables 4.1-3 and 4.1-4, respectively. Weight equations for both are included in the tables.

Power is required for the redundant preamplifiers in the receive MBA. The required power level is 0.75 Watts per assembly, therefore the total power required by the receive MBA is

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Table 4.1-38. HYBRID System Payload Power Amplifier Requirements (0.995 Availability, Zone D)

- EIRP (0.995) = 47.7 + 10 Log DR/1.544 Mbps (where DR is the data rate)
- Transponder Loss Budget

- Waveguide	0.3 dB
- Bandpass Filter	0.5
- Isolator	0.3
- Redundancy Switch	0.3
- Antenna Waveguide	0.2
- Antenna/Transponder Mismatch Loss	0.3
Transmitter Losses, L_T =	1.9 dB

- TWTA Power Required is: P_{TWTA} = EIRP - G_T + L_T

P_{TWTA} (0.995) = 49.6 dBw + 10 Log DR/1.544 Mbits/sec - G_T

and G_T is the transmit antenna contour gain in dBi.

Number of Beams	Cell Diameter (Degrees)	G_T (dBi) at Adjacent Cell Contour	TWTA Power (dBw) per T-1 Carrier (1.544 Mbps)
13	1.21	37.54	12.06
19	1.0	39.2	10.40
32	0.77	41.47	8.13
46	0.64	43.08	6.52
68	0.53	44.71	4.89
100	0.44	46.33	3.27
178	0.33	48.83	0.77

For 0.999 Availability - Add 0.5 dB to TWTA Power

For 0.9995 Availability - Add 5.2 dB to TWTA Power

Saturated output of TWTA is 6 dB higher

Normalized to 1 meter Earth Station antenna and 1.544 Mbps. For Earth Station antenna other than 1 meter diameter, subtract 20 log D from last column, D = meters.

$$P_A = 0.75\ N_F\ \text{Watts}$$

where N_F is the number of feeds.

Payload Weight and Power Summaries

A summary of the weight and power equations appears in Table 4.1-39, parametric in number of antenna beams, N_B, number of channels N_{CH} and the data rate D_R.

The HYBRID system is relatively heavy since it has the extensive channelization characteristics of SS-FDMA as well as the burden of the baseband processor. Although the TWTAs operate more efficiently than in FDMA and, hence, the weight and power is less, the decreased TWTA requirements do not offset this increased burden.

Table 4.1-40 shows the equations which are the sums of the terms in Table 4.1-39 and used directly for computing weight and power in Figure 4.1-29.

4.1.4 SS-TDMA/SCANNING BEAM SYSTEM CONCEPT

SS-TDMA/Scanning Beam is an adaption of TDMA in which scanning spot beams are used to establish communications between individual earth stations. This approach provides high satellite antenna gain and full coverage but introduces the need for burst mode operation of the earth station.

With respect to the S/C payload, the basic approach involves the use of an onboard processor to store the data received on a scanning beam and forward the data, after reformatting, when a second, transmitting scanning beam is in the correct position. TDMA/FDMA is used in the uplink and TDM in the downlink. In this system, the entire data frame is stored in the satellite resulting in a processor with large memory and high speed operation requirements resulting in high power consumption. Scanning is accomplished by a fixed contiguous beam multibeam antennas with IF switching for receiving and ferrite switched corporate feed networks for transmitting.

If a single scanned beam is used, then interference from co-channel beams is eliminated at the expense of increased burst rates. To increase capacity, several scanned beams are used to reduce the uplink burst rates and downlink data rates.

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Table 4.1-39. Summary of Weight and Power Equations
For a Hybrid (FDMA Uplink/TDMA Downlink) System with Fixed Beams

Item	Quantity	Total Weight (Pounds)	Total Power (Watts)
Receive Antenna	1	$0.87N_F + 0.8$ Art + 3.37 DR+15	$0.75\ N_B$
2nd D/C (Receiver)	1/Beam	$0.68N_B$	$0.45\ N_B$
3rd D/C	3/Beam	$0.42N_B$	$0.9\ N_B$
Rec Channel Units and DC Modulators	See Last Column of Table 4.1-35	$0.274\ N_{ch}$	$1.0\ N_{ch}$
Baseband Processor	1	0.073 DR(Mbps)	0.258 WATTS X DR (Mbps)
Control and Signalling	1	4.0	4.0
Local Oscillators	See Table 4.1-37	11.2 + 0.0438 DR + $0.309\ N_B$	35.3 + 0.0004 DR + $0.196\ N_B$
QPSK Modulator	1/Beam	$0.3\ N_B$	-
Final Upconverter & DRWER Assembly	1/Beam	$0.98\ N_B$	$0.7\ N_B$
Transmitter Output Assemblies	1/Beam	$1.68\ N_B$	-
Transmit Antenna	1	$0.99\ N_F + 0.8A_R$ + 3.37 DR + 15	-
TWTA	1/Beam + Red.	$0.106\ Wrf + 6\ N_B$ (W_{rf} from Table 4.1-38)	2.5 Wrf
Subtotals			
Harness (2%)			
Brackets Boxes (1%)			
Low Voltage Power Supply (1%)			
Contingency 10%			
Total			

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Table 4.1-40. FDMA (Uplink)/TDMA (Downlink) Weight & Power Functions

Weight (Pounds)		=	$45.2 + 5.04\ N_B + 12.94\ N_B + 0.274\ N_{ch} + 0.1168\ DR + (EIRP)\ (DR/N_B)\ (1/D')^2 \times 2.43\times10^{-4}$
Power (Watts)		=	$39.3 + 3.0\ N_B + 1.0\ N_{ch} + 0.2584\ DR + (EIRP)\ (DR/N_B)\ (1/D')^2 \times 5.73 \times 10^{-3}$
where	N_B	=	Number of Beams
	DR	=	Data Rate
	N_{ch}	=	Number of Switched Channels (See Table 4.1-35)
	EIRP	=	Numerical value from Table 4.1-38
	D'	=	Earth Station antenna diameter in meters

NOTE: 14% added to account for harness, brackets and boxes, LVPS, and contingencies.

Signalling is accomplished in a scanner/processor in the same way that normal communication occurs. The transmitting station communicates with the Net Control Center (NCC) in a pre-assigned time slot of the frame and requests a communication link to a specific destination. The NCC responds to the requestor in a manner analagous to TDMA, assigning transmitting and receiving time slots, timing data, satellite drift update as well as normal signalling information.

Thus, the Network Control Center performs the functions of a routing calls, billing, rendering operator assistance, busying out and monitoring traffic intensity.

The previous discussion of the SS-TDMA/Fixed Beam system showed that the use of low burst rates has not achievable for all user classes unless extensive channelizing is used, which required frequency division multiplexing of the uplinks and downlinks. Along with the use of multiple uplink and downlink beams, in the SS-TDMA/Scanning Beam multiple carrier frequencies are assigned to each beam. Since the aggregate rate is unchanged and there will only be a few scanning beams and a few transponder channels, the data rate per beam will be high, placing large burdens on the power amplifiers and the payload processor. Both scanning beams and fixed beams can be used. In general, a scanning beam is used in areas where traffic densities are moderate and fixed beams are used where traffic densities are high. Scanning beams do not visit a fixed beam area, therefore the fixed beams must have capacity equivalent to the traffic in the area to be served.

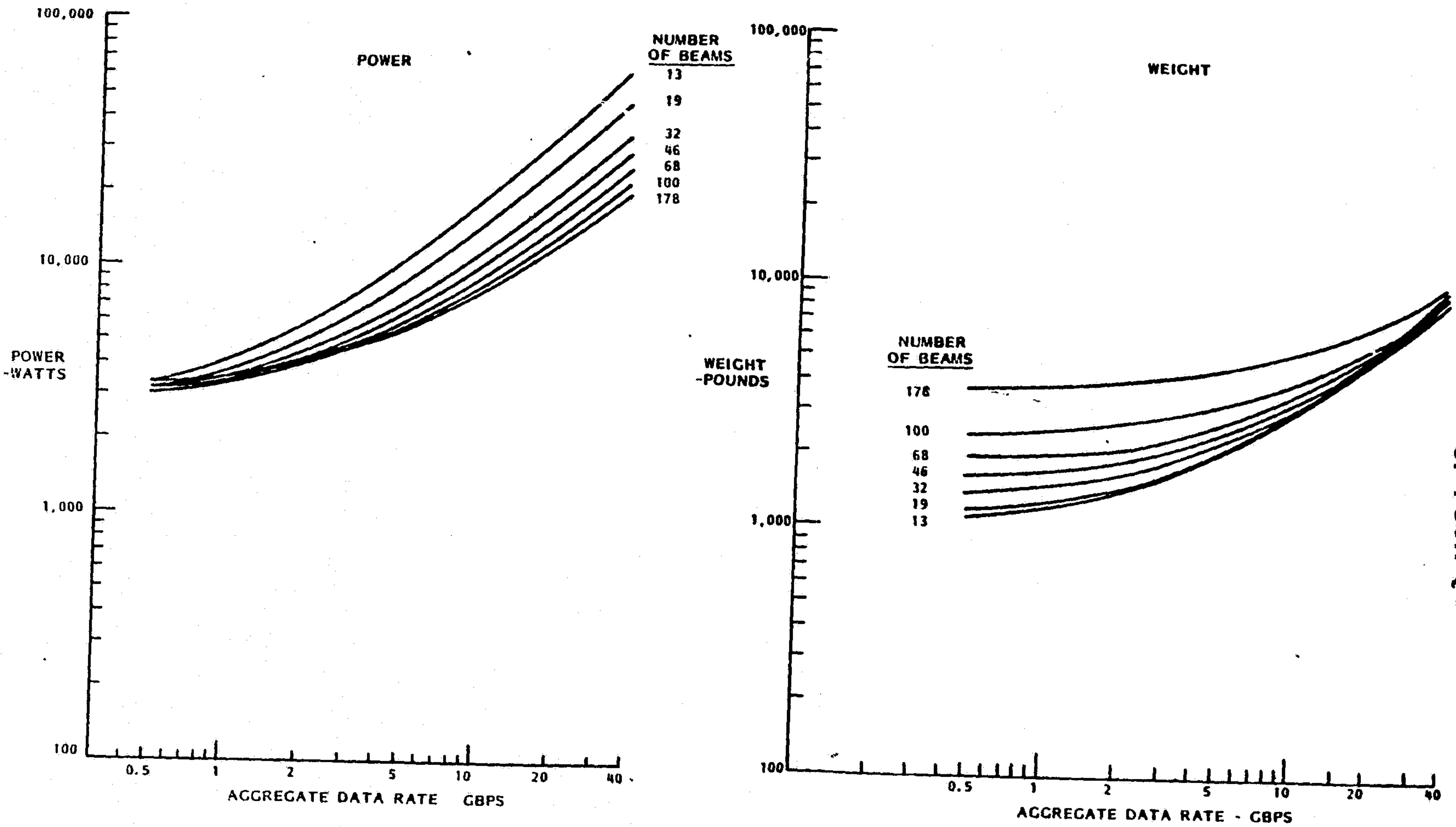

Figure 4.1-29. Hybrid FDMA Up/TDMA Down System
Payload Weight and Power Summary

Each beam, whether scanning or fixed, is channelized as necessary to be compatible with the input rates of the Motorola baseband processor. Processor requirements are scaled from the existing weight and power projections for 1987 technology as published by Motorola. There is one scanning beam per sector and multiple fixed beams in regions where the traffic is high. Each scanning beam will be under microprocessor control with stored program operation and capability to update the scanning program.

Scanning of each sector will occur in a few milliseconds. Switching between parts of the multibeam antenna to achieve beam scanning will occur in less than 1 u sec and will nominally be about 10 nanosec.

SS-TDMA/Scanning Beam systems have the transmission formats shown in Figure 4.1-30. The frame time is the time allocated for scanning one sector, e.g., 1 millisecond. The scan cycle repeats for the duration of the round trip propagation time to the satellite. This defines a superframe of 512 frames which corresponds to the propagation time in the example shown. Instructions for any reconfiguration of the baseband processor elements or the earth terminals are executed at the beginning of a superframe.

While a scanning beam dwells on a particular area, all stations in that area that have been assigned the same transmit carrier frequency access the satellite via TDMA. Each station transmits a preamble, which includes guard time; carrier and clock recovery bits; a unique word for timing error measurements and phase ambiguity resolution; and orderwire data for transmitting terminal status, health, requests for the use of error correction coding, changes in capacity requirements and so on. Following the preamble the traffic information is transmitted. Included here is the supervision and control information for call setup and takedown. This relieves the NCC of those functions, however the NCC assigns the required system resources and configures the system.

The downlink frame is organized in the same fashion except that only one preamble is required for each area and the orderwire may be shared by the terminals in an area.

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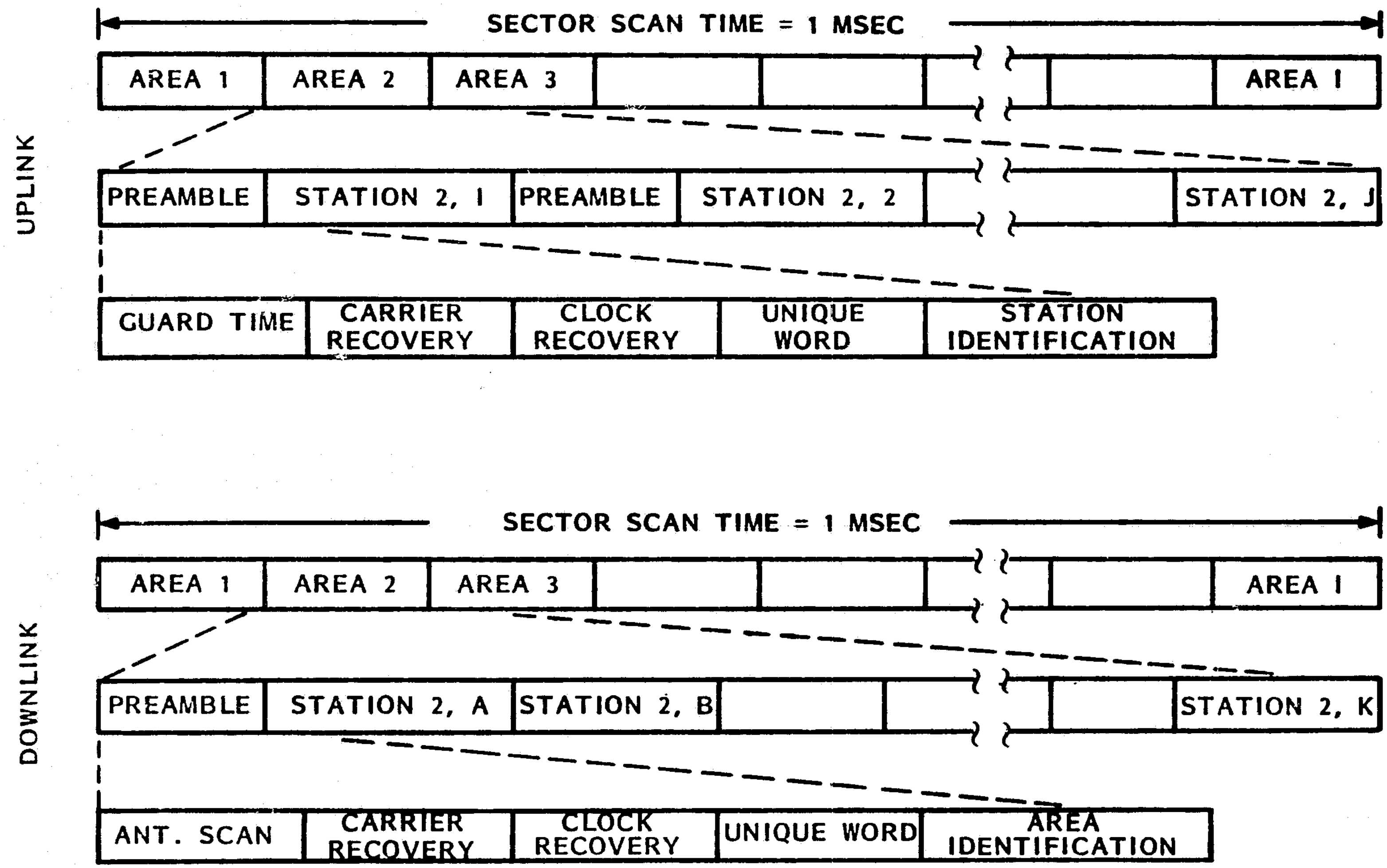

• UPLINK AND DOWNLINK DO NOT NECESSARILY COVER THE SAME AREA SIMULTANEOUSLY.

Figure 4.1-30. SS-TDMA/Scanning Beam Frame Formats

The previous TDMA analysis showed the total overhead to be approximately 25% of the total frame time. Therefore, the effective thoughput rates for any scanned area is 75% of the burst rate when summed over all terminals in the area.

The Motorola processor rates are shown in Table 4.1-41. Note that the throughput of a single earth station is substantially less than the aggregate values shown. If there are 20 earth stations within the spot beam, then the average throughput per earth station is necessarily 1/20th of the above values.

Table 4.1-41. Baseband Processor Rates vs Area ThroughPut Rate

Earth Station and Processor Burst Rate (Mbps)	Throughput Rate of the Scanned Area (Mbps)
27.5	20.6
55.	41.25
110	82.5
220	165.0
440	330
550	412.5

Figures 4.1-31, -32 and -33 demonstrate how the United States may be partitioned to operate with a TDMA scanning beam system on the basis of equivalent 46,68, or 100 beams, using an aggregate traffic rate of 5 Gbps. Tables 4.1-42, -43 and -44 summarize the channel requirements for 46, 68 and 100 beam systems.

Because of the high data rates, frequency division multiplexing of the TDMA uplinks is required, however, it is not possible to achieve very low data rates unless many more parallel channels are added, as with the fixed beam TDMA system. Therefore the terminals and the satellite will need to support relatively high data rates.

It is noted that natural spatial separation occurs between scanning beams and frequencies can be re-used in alternate sectors. If clever scanning strategies are employed, the frequencies can actually be reused in adjacent sectors.

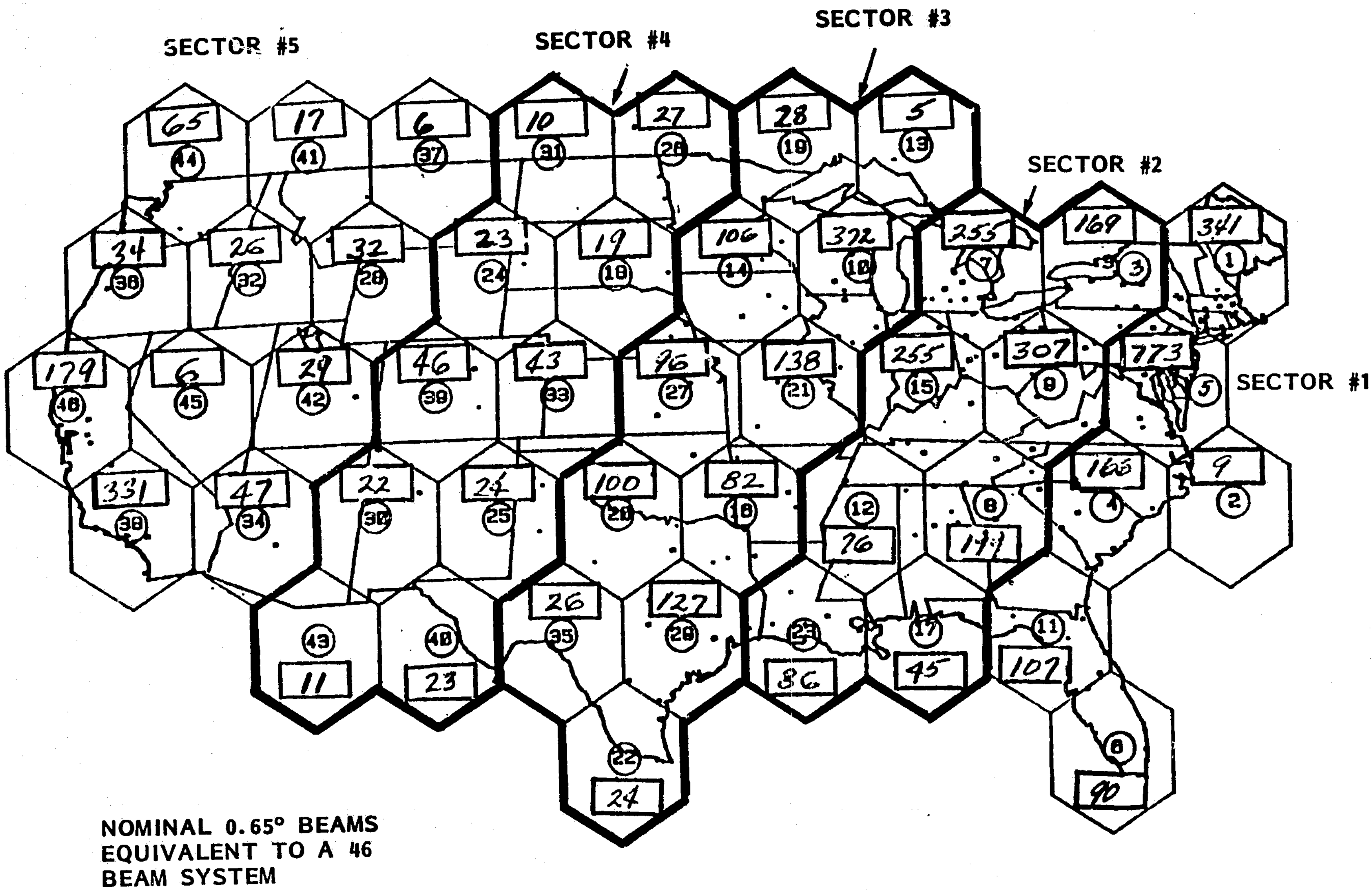

Figure 4.1-31. Sector Scan With 5 Scanning Beams and CPS Busy Hour Traffic of 5 Gbps (46 Beam Positions)

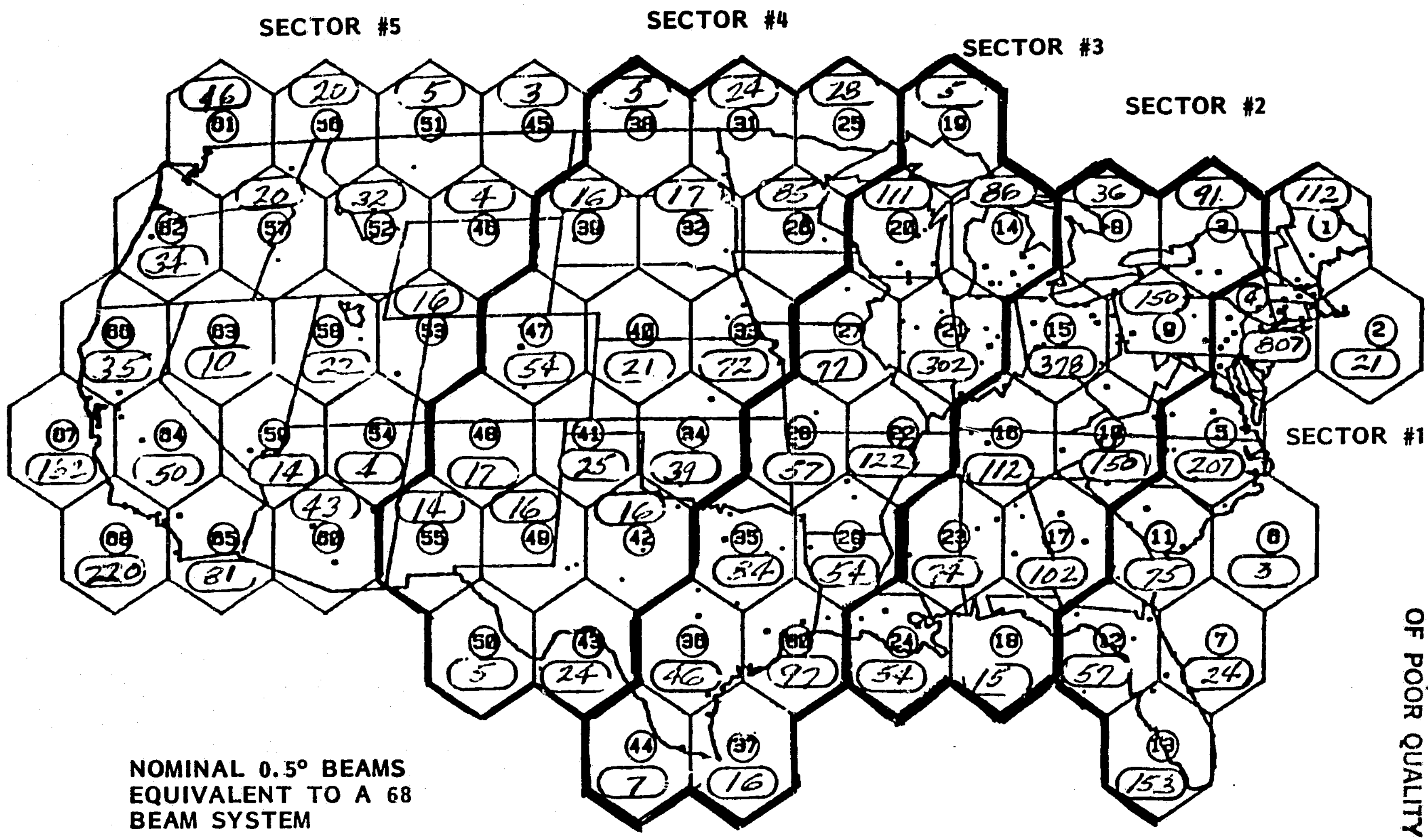

Figure 4.1-32. Sector Scan With 5 Scanning Beams and CPS Busy Hour Traffic of 5 Gbps (68 Beam Positions)

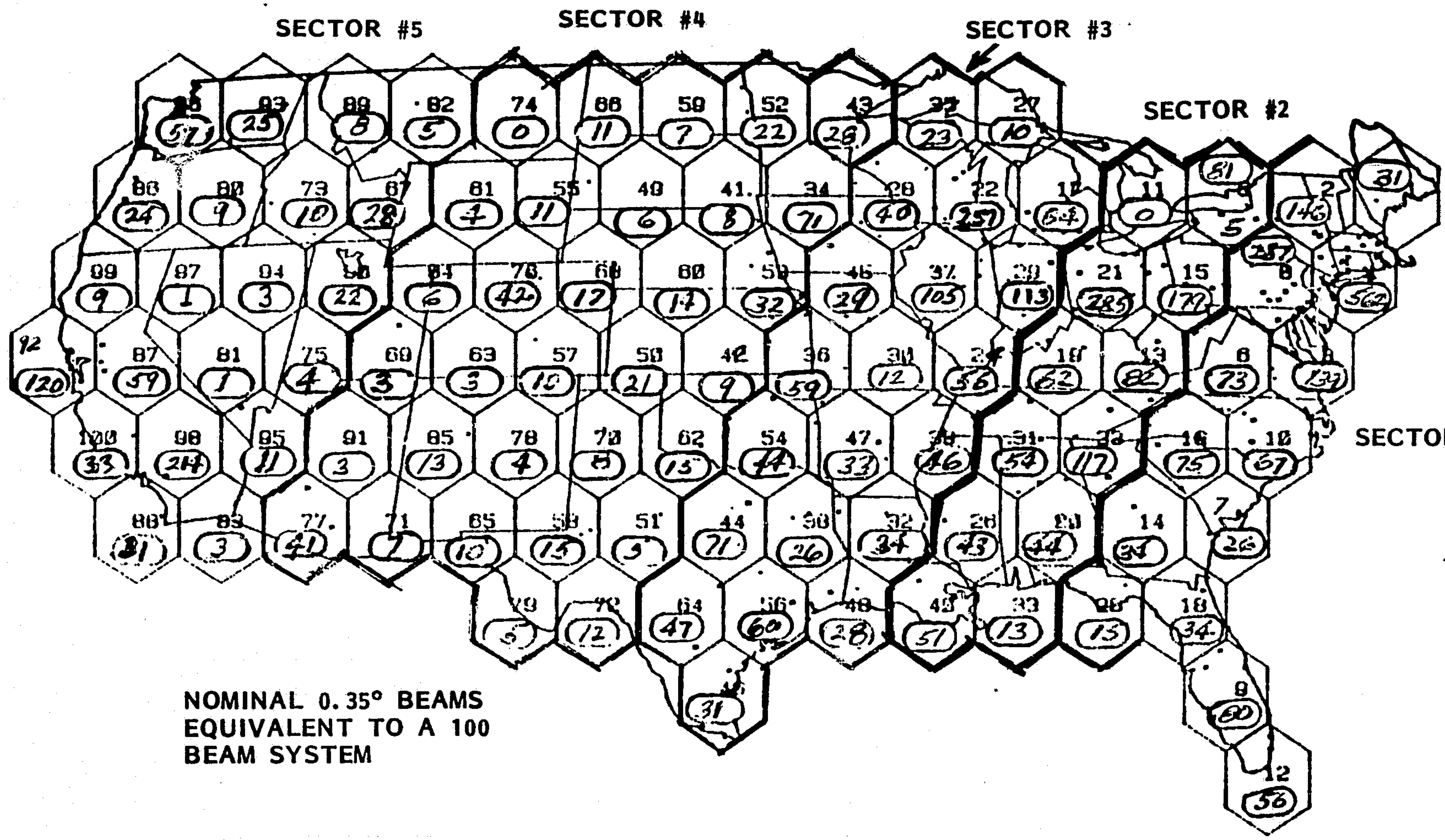

Figure 4.1-33. Sector Scan With 5 Scanning Beams And CPS Busy Hour Traffic of 5 Gbps (100 Beam Positions)

Table 4.1-42. Scanning Beam & Fixed Beam Requirements-46 Beam Equivalent System

Sector ID	Beam ID	Aggregate Sector Rate (Mbps)	Scan Beam Rate*(Mbps)	Fixed Beam Rate*(Mbps)	Summary
1	1,5,2,4, 11,8	1486	Channelize with: 1-550 Mbps 2-220 Mbps	Beam #5 2-550 Mbps	1 Fixed Beam (2 Ch) 1 Scanner with 3 FDM channel
2	3,7,9.15,8, 12,17,23	1392	Channelize with 3-440 Mbps 1-110 Mbps	Beam 9 440 Mbps 440 Mbps	1 Fixed Beam (1 ch) 1 Scanner with 4 FDM channels
3	13,19,10,14 21,27,16,20 29,35,24	1104	Channelize with 2-440 Mbps 1-110 Mbps	Beam #10 550 Mbps	1 Fixed Beam (1 ch) 1 Scanner with 3 FDM channels
4	26,31,18,24 33,39,11 25,30,40 43	248	Channelize with 2-220 Mbps	None	No fixed beam 1 Scanner with 2 FDM channels
5	37,41,44 28,32,36 42,45,46 34,38	772	Channelize with 3-220 Mbps	Beam No. 38 550 Mbps	1 Fixed Beam (1 ch) 1 Scanner with 3 FDM channels

The 46 equivalent beam system uses 4 fixed beams, 5 fixed beam transponder channels, 5 scanning beams and 15 scanning FDM channels

* Refer to peak rates. Throughout is 75% of the peak rates.

Table 4.1-43. Scanning Beam And Fixed Beam Requirements - 68 Beam Equivalent System

Sector I.D.	Beam I.D.	Aggregate Rate (mbps)	Scan Beam Rate*(Mbps)	Fixed Beam Rate (Mbps)	Summary
1	1,2,4,5,6 11,7,12,13	1459	Channelize with 3-440 Mbps 1-220 Mbps	Beam #4 2-550 Mbps	1 Fixed Beam (2 ch) 1 Scanner with 4 FDM channels
2	3,8,9,15 10,16,17,23, 18,24	1112	Channelize with 2-440 Mbps 1-110 Mbps	Beam #15 1-550 Mbps	1 Fixed Beam (1 ch) 1 Scanner with 5 FDM channels
3	14,19,20,21,22 27,28,29,35, 30,36,44,37	1064	Channelize with 2-440 Mbps 1-220 Mbps	Beam #21 1-440 Mbps	1 Fixed Beam (1 Ch) 1 Scanner with 3 FDM Channels
4	25,31,38,26 32,38,33,40,47 34,41,48,42,49 55,43,50	478	Channelize with 2-220 Mbps 2-110 Mbps	None	No Fixed Beam 1 Scanner with 4 FDM Channels
5	45,51,56,61,46 52,57,62,53 58,63,66,54, 59,84,87,60, 65,68	821	Channelize with 1-440 Mbps 4-220 Mbps	Beam #68 1-440 Mbps	1 Fixed Beam (1 Ch) 1 Scanner with 5 FDM Channels

The 68 equivalent beam system uses four fixed beams, five fixed transponder channels, five scanning beams, and 19 scanning FDM channels

* Refers to peak rates. Throughput is 75% of the peak rate.

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Table 4.1-44. Scanning Beam And Fixed Beam Requirements 100 Beam Equivalent System

Sector ID	Beam ID	Aggregate Sector Rate (Mbps)	Scan Beam Rate* (Mbps)	Fixed Beam Rate (Mbps)	Summary
1	1,2,4,8,6, 3,10,16,7,14, 18,20,9,12	1645	Channelize with: 3-440 Mbps 2-220 Mbps	Beam #4 1-550 Mbps 1-220 Beam #8, 2-220 Mbps	2 Fixed Beams (2 Ch each) 1 Scanner with 5 FDM Channels
2	5,11,15,21, 13,19,22, 31,20,26, 33,40	935	Channelize with: 4-440 Mbps	Beam #21 440 Mbps	1 Fixed Beam (1 Ch) 1 Scanner with 4 FDM Channels
3	35,27,28,22, 17,46,37,29, 36,30,24,54, 47,39,44,38, 32,64,56,48, 31	1205	Channelize with: 3-440 Mbps	Beam #22 1-440 Mbps	1 Fixed Beams (1 Ch) 1 Scanner with FDM Channels
4	74,66,59,52, 43,81,55,49, 41,34,84,78, 68,60,59,69, 63,57,50,42, 91,85,78,70, 62,77,71,65, 58,51,79,72,	376	Channelize with 2-220 Mbps 1-100 Mbps	None	No Fixed Beam 1 Scanner with 3 FDM Channels
5	96,93,89,82, 86,80,73,67, 99,97,94,90, 92,87,81,75, 100,98,95,88, 83	677	Channelize with 2-220 Mbps 1-55 Mbps	Beam #92 1-220 Mbps Beam #98 1-220 Mbps 1-110 Mbps	2 Fixed Beams (3 Ch) 1 Scanner with 3 FDM Channel

The 100 equivalent beam system uses six fixed beams, nine fixed beam transponder channels, five scanning beams and 18 scanning FDM channels.

* Refers to peak data rates. Throughput is 75% of the peak rate.

The total number of channels required by the scanning beam system is given in Table 4.1-45. The relatively high data rate results from a payload that is not highly channelized.

An implementation concept for the TDMA Scanner Processor System is shown in Figure 4.1-34.

A summary of the hardware required to implement the system is contained in Table 4.1-46.

Table 4.1-45. Summary of Scanning Beam Channelization

Equivalent No. of Beams	No. of fixed Beams	No. of Scanning Beams	Channels With Fixed Beams (Mbps)	Channels With Scanning Beams (Mbps)	Total Channels
46	4	5	4-550 1-440	1-550 5-440 7-220 2-110	20
68	4	5	3-550 2-440	8-440 8-220 3-110	24
100	6	5	1-550 2-440 5-220 1-110	10-440 6-220 1-110 1-55	27

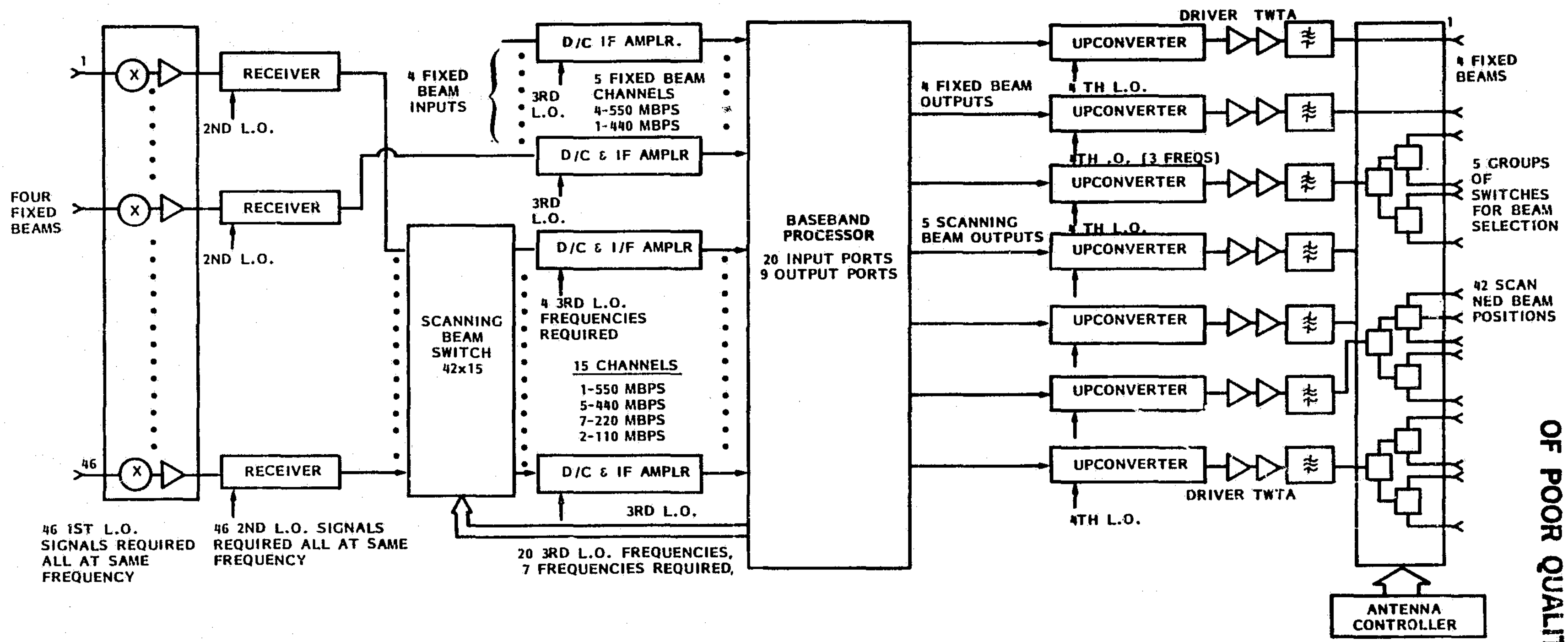

Figure 4.1-34. Payload Block Diagram for a TDMA Scanner Processor System, 46 Beam Positions and 5000 Mbps Aggregate Rate

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Table 4.1-46. Hardware Matrix For A TDMA Scanner Processor System

Number of Recv Beam Position	Fixed Beams	Scanning Beams	Number of Receivers	No. of D/C & IF Amplifiers(1)	Processor Outputs Fixed Beams	Scan. Beams	Upconvertors(2)	Drivers & TWTAs(2)	Transmitter(2) Output Assemblies	Transmit MBA Fixed Beams	Transmit MBA Scanning Beams	Transmit MBA Variable Switch Assemblies	Transmit MBA Total No. of Switches	Dimensions of Scanning Beam Switch For 5000 Mbps
46	4	5	46	20	4	5	9	9	9	4	42	5	41	42 x 15
68	4	5	68	24	4	5	9	9	9	4	62	5	61	62 x 19
100	6	5	100	27	6	5	11	11	11	6	94	5	93	94 x 18

(1) Proportional to Aggregate Data Rate

(2) Equal to the Sum of Fixed Beams and Scanning Beams

Table 4.1-47. Candidate Receive Antenna Characteristics

ACTIVE RECEIVE MBA	ACTIVE BEAM SWITCHED MBA	BFN SWITCHED MBA
• REQUIRES ONLY 1 RECEIVER	• REQUIRES 1 RECEIVER/BEAM	• REQUIRES ONLY 1 RECEIVER
• ADJUST AMPLITUDE & PHASE WEIGHTS FOR EACH VPD, ONCE/FRAME	• GENERATE ADDRESS AND SWITCH COMMAND	• ADJUST AMPLITUDE & PHASE WEIGHTS FOR EACH VPD, ONCE/FRAME
• LOW NOISE FRONT END ON EACH ELEMENT TO MAXIMIZE G/T & REDUCE EARTH TERMINAL EIRP	• LOW NOISE FRONT END ON EACH ELEMENT TO MAXIMIZE G/T	• LOW NOISE FRONT END FOLLOWING BFN. LOWER G/T THAN OTHER APPROACHES.
• SWITCHING TIME ≈100 NANOSEC	• SWITCHING TIME ≤ 1 NANOSEC POSSIBLE	• SWITCHING TIME ≈ 100 NANOSEC TO A FEW SEC
• BEAMS CAN BE SHAPED TO ELIMINATE CROSSOVER LOSS PROBLEM	• FORMS SPOT BEAMS DISTRIBUTED OVER CONUS, 4.5 TO 7 dB LOSS AT DOUBLE & TRIPLE CROSSOVERS, RESPECTIVELY.	• BEAMS CAN BE SHAPED TO ELIMINATE CROSSOVER LOSS PROBLEM
• SUPPORT ONE SCANNING BEAM AT A TIME	• SUPPORT MULTIPLE SCANNING OUS SCANNING BEAMS TO INCREASE THRUPUT	• SUPPORT ONE SCANNING BEAM AT A TIME
• REQUIRES COMPLEX L.O. DISTRIBUTION NETWORK & HIGH-POWER L.O.	• REQUIRES COMPLEX L.O. DISTRIBUTION NETWORK & HIGH POWER L.O.	• SINGLE PORT LOW - POWER L.O. REQUIRED

Weight And Power Requirements

Component weight and power requirements for this system are largely identical to those described for the other systems. The following contains a brief description of the hardware and provides rules for extending the results to more complex systems.

The active beam-switched antenna configuration has been chosen on the basis of the trades in Table 4.1-47. Weight and power requirements for this antenna are given in Table 4.1-48 and are identical to the other configurations.

The Receiver and Second Downconverter units are identical to those derived in Tables 4.1-16 of the SS-FDMA Section 4.1.1.

$W = 0.68\ N_B$ Pounds
$P = 0.75\ N_B$ Watts

The 3rd downconverter and IF Amplifier converts the frequency division multiplexed TDMA uplinks to a common X-band IF and provides IF amplification. Weight and power requirements of each unit are identical to the receiver and 2nd downconverter, however, the total requirements are proportional to the number of channels.

$W = 0.68\ N_{ch}$
$P = 0.45\ N_{ch}$

The scanning beam switch dimensions are a function of the number of scanning beams and the number of channels employed for the scanning beams. Its' purpose is to provide connectivity between the terminals located at specific beam positions and the demodulators in the baseband processor, using an I.F. interface. Tradeoffs for various switch implementations have been discussed in Section 4.1.2 of the SS-TDMA system description. Power and weight requirements are specified in terms of the number of switch crosspoints.

$W = 1.25 \times 10^{-3}$ Pounds/switchpoint
$P = 1.4 \times 10^{-2}$ Watts/switchpoint

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Table 4.1-48. Calculated Weight For 30 GHz Receive Antenna Assembly

No. of Beams	Reflector Diameter (in/Meters)	No. of Feed Horns	Reflector Area (ft^2)	Reflector Weight (Pounds)	Boom and Structure Weight (Pounds)	Hinge Weight (Pounds)	Feed Horn Weight (Pounds)	Platform Weight (Pounds)	Waveguide Weight (Pounds)	D/C & Preamp (Weight)	Antenna Weight (Pounds)
13	24.8/0.63	13	3.35	2.35	6.97	0.34	0.26	16.3	7.41	2.34	36.0
19	30/0.76	19	4.9	3.43	8.43	0.49	0.38	16.9	10.83	3.42	43.9
32	38.9/0.99	32	8.25	5.78	10.92	0.82	0.64	18.2	18.24	5.76	60.4
46	46.7/1.19	46	11.89	8.33	13.12	1.19	0.92	19.6	26.22	8.28	77.7
68	56.8/1.44	68	17.60	12.32	15.95	1.76	1.36	21.8	38.76	12.24	10.42
100	68.8/1.75	100	25.82	18.07	19.32	2.58	2.0	25.0	57.0	18.00	142.0
178	91.8/2.33	178	45.96	32.17	25.78	4.60	3.56	32.8	101.46	32.04	232.4

Nominal Frequency is 28 GHz

Reflector Weight = 0.7 A_R pounds, where A_R is the reflector area in square feet

Boom and Structure Weight = 3.37 D_R pounds, where D_R is the reflector diameter in feet

Power Hinge = 0.1 A_R Pounds

Feed Horn Weight = 0.02 N_F pounds where N_F is the number of feedhorns

Weight of first downconverter and preamp is 0.18 pounds. Each unit requires 0.75 watts regulated DC power.

Waveguide weight = 0.57 N_F pounds (10 ft lengths)

Antenna Weight, $W_A = N_F\ (0.1 + 0.02 + 0.57 + 0.18) + A_R\ (0.7 + 0.1) + 3.37\ D_R + 15$ pounds

W_A (28 GHz) $= 0.87\ N_F + 0.8\ A_R + 3.37\ D_R + 15$ pounds

Power $= 0.75\ N_F$

Alternatives to the crossbar configuration have been widely discussed in the previous configuration and are provided for guidance in Table 4.1-49. Note that the penalty for selecting a crossbar switch with up to 6000 crosspoints is not significant. The number of crosspoints required is a function of the agregate data rate and the antenna configuration.

Recalling that the number of switch inputs is equal to the number of scanning beams and that the number of switch outputs is proportional to data rate, the switch dimensions may be approximated in the following way.

Table 4.1-49. Comparison of Weight And Power Needs For Crossbar and CLOS Switch Configurations

No. of Switchpoints		Switch	
Crossbar	Clos, 3 Stage N = 0	Weight (Pounds)	Power (Watts)
5	75	1.(MIN)	0.08
11	98	1	0.15
30	156	1	0.4
120	153	1	1.7
480	694	1	6.7
1080	1111	1.4	15.1
1920	1575	2.0	22.1
7680	3900	4.9	54.6
30	156	1 (MIN)	0.2
77	255	1	0.53
307	540	1	2.1
1733	1479	2.0	10.1
6750	3569	4.9	24.4
15,323	6383	8.8	43.7
27,000	9774	13.5	66.9
108,000	30,094	41.5	205.8
30	156	1 (MIN)	0.2
77	255	1	0.53
270	503	1	1.9
1470	1338	1.8	9.2
5713	3186	4.4	21.8
12,731	5577	7.7	38.2
22,523	8509	11.7	58.2
89,435	25,658	35.4	175.5

No of Crosspoints = Ni x Nch

$$46 \text{ Beams: } 42 \left(\frac{DR}{5000}\right) \times 20$$

$$68 \text{ Beams: } 64 \left(\frac{DR}{5000}\right) \times 24$$

$$100 \text{ Beams: } 94 \left(\frac{DR}{5000}\right) \times 27$$

Where DR is the data rate in Megabits per second. DR/5000 represents the sensitivity to the number of channels Nch and the baseline quantity at 5000 Mbps.

Weight and power requirements for the Baseband Processor are based upon the Motorola technology projections for 1987. The Motorola predictions are for 225 pounds and 800 watts for a processor having throughput capability of 3410 Mbps*.

W = 250 pounds/3410 Mbps = 0.073 pounds/Mbps
P = 800 watts/3410 Mbps = 0.235 watts/Mbps

The upconverters and driver assembly is identical to that used for the SS-FDMA system Section 4.1.1.

Weight = 0.98 N_b Pounds
Power = 0.7 N_b Watts

Note that the number of beam positions, N_b, is not the same as the number of beams. For the scanning system,

$$N_b = N_{fb} + N_{sb}$$

when N_{fb} is the number of fixed beams and N_{sb} is the number of scanning beams. Refer to the hardware matrix of Table 4.1-46 to verify the correct value. For the cases considered:

*"30/20 GHz Communications System, Baseband Processor Subsystem", Task I, Communication Subsystem Design, Interim Report, p 11-12, Nov. 18, 1980.

Beam Positions	N_B
46	9
68	9
100	11

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TWTA and Output Assemblies: EIRP requirements are derived in Table 4.1-50. Because there are few carriers per TWTA, the tube can be operated in saturation. Each beam will have a continuous downlink data streams permitting continuous demodulation in the earth station after initial synchronization required when the beam arrives at the earth station.

TWTA weight is identical to all other configurations

$$W_{TWTA} = (0.106\ W_{re} + 6)\ \text{Pounds}$$

$$P_{TWTA} = 2.5\ W_R = \text{Watts (40\% Efficiency)}$$

Economies of scale are expected to apply such that the above provides for shared redundancy. The transmitter output assemblies include redundancy switches and weigh 1.68 pounds for each beam.

Switch losses in the antenna will reduce the available EIRP. The anticipated penalty for switching beam is as follows:

Number of Beams	Number of Scanned Beam Positions	Typical Number of Switch Layers in Network	Switch Loss (dB)
46	42	5	1.0
68	62	5	1.0
100	94	6	1.2

Local oscillator assembly requirements are specified in Table 4.1-51.

Weight and power requirements for the Transmitting Antenna are summarized in Table 4.1-52. With the exception of a network to rapidly switch the beams, the antenna is similar to the other configurations. Insertion losses of the switches influence the EIRP, as noted previously.

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Table 4.1-50. CPS SS-TDMA Scanner Processor Power Amplifier Requirements (0.995 Availability, Rain Zone D, Normalized To A 1 Meter Diam. E.S. Antenna And T-1 Channel (1.544 Mbps)

(0.995 Availability, Rain Zone D, Normalized to A
1 Meter Diameter Earth Station Antenna & T-1 Cahnnel (1.544 Mbps)

- EIRP = 47.5 dB + 10 log (DR/1.544) where DR is Data Rate, Mbps.
- Transponder Loss Budget
  - Waveguide 0.3 dB
  - Bandpass filter 0.5
  - Isolator 0.3
  - Redundancy Switch 0.3
  - Antenna Waveguide 0.2
  - Antenna Transponder Mismatch Loss 0.3
  - Beam Switch Loss 1.0 (to 68 beams) or 1.2 (100 beams)

  2.9 or 3.1
- TWTA Power = EIRP - G_T + L_T
  = 47.5 - 10 log (DR/1.544)-G_T
  + 2.9 or 3.1

Where G_T is the gain at the contour intersection with an adjacent beam (subtract 20 log D' for Earth Station Antenna Diameter D' ≠1 meter)

Number of Beams	Cell Diameter (Degrees)	G_T(dBi) at Adjacent Cell Contour	TWTA Power per T-1 Carrier
13	1.21	37.54	*
19	1.0	39.2	*
32	0.77	41.47	*
46	0.64	43.08	7.3
68	0.53	44.71	5.7
100	0.44	46.33	4.3
178	0.33	48.83	*

* Tentatively not considered for this sytem. Add 3.6 dB for 0.999 availability and 11.6 dB for 0.9995; add 1.7 dB for satellite average over CONUS. With diversity in Earth Station net, no addition required for any availability.

Table 4.1-51. Local Oscillator Assemblies Weight And Power Estimates

Item	Quantity Required	Unit Weight -Pounds	Total Weight -Pounds	Power -Watts
Frequency Standard	2	0.8	1.6*	1.5
9.5 GHz Local Oscillator (1st Downconverter)	2	1.25	2.5*	11.0
9.5 GHz Amplifier	2	0.1	$0.4N_B/13$*	$0.3N_B/13$
9.5 GHz Power Divider and Coax	1	-	$0.106N_B/13$	-
9.5 GHz Amplifier	1/BEAM	0.1	$0.2N_B$	$0.15N_B$
8.5 GHz Local Oscillator	2	1.25	2.5*	11.0
8.5 GHz Amplifiers	2	0.1	$0.4N_B/13$	$0.3N_B/13$
8.5 GHz Power Divider/ Combiner	2	-	$0.106N_B/13$	-
70.0 MHz Source (Transmitter)	2	1.0	2.0	1.0
500 MHz Local Oscillator (XMT)	2	0.3	0.6	0.5
LO For Third Downconverter	3	0.5	1.5	9.0
Amplifier for Third D/C	3	0.1	0.3	0.3
Power Divider	0.026DR	0.05	0.0013DR	-
Coaxial Cable (Feet)	0.005DR	0.1	0.0005DR	-

Weight = $11.0 + 0.0018\ DR\ (Mbps) + 0.2\ N_B + 1.012\ N_B/13$

Weight = $11.0 + 0.0018\ DR\ (Mbps) + 0.278\ N_B$ POUNDS

Power = $34.3 + 0.0004\ DR\ (Mbps) + 0.6\ N_B/13 + 0.15\ N_B$

Power = $34.3 + 0.0004\ DR\ (Mbps) + 0.196\ N_B$ WATTS

N_B = Number of Beams; DR = Data Rate In Mbps

*Includes Redundancy

Table 4.1-52. Calculated Weight For 20 GHz Transmit Antenna Assembly

No. of Beams	Reflector Diameter (In/Meters)	No. of Feed Horns	Reflector Area (ft^2)	Reflector Weight (Pounds)	Boom and Structure Weight (Pounds)	Power Hinge Weight (lbs)	Feed Horn Weight (Pounds)	Feed Platform Weight (Pounds)	Waveguide Weight (Pounds)	Number of Switches	Switch Weight	Control Processor Weight	Control Processor Power	Antenna Weight (Pounds)
13	38.6/0.98	13	8.13	5.69	10.84	0.81	0.39	16.3	11.18	11	8.8	1.43	4.4	55.6
19	46.7/1.19	19	11.88	8.31	13.12	1.19	0.57	16.9	16.34	14	11.2	2.15	5.6	69.9
32	60.6/1.54	32	20.00	14.00	17.02	2.00	0.96	18.2	27.52	27	21.6	3.70	10.8	105.1
46	72.6/1.84	46	28.75	20.13	20.39	2.88	1.38	19.6	39.56	41	32.8	5.37	16.4	142.2
68	88.3/2.25	68	42.51	29.76	24.80	4.25	2.04	21.8	58.48	61	48.8	8.00	24.4	198.0
100	107.1/2.72	100	62.51	43.76	30.08	6.25	3.0	25.0	86.00	93	74.4	11.82	37.2	280.3
178	142.8/3.63	178	111.22	77.89	40.10	11.12	5.34	32.8	158.03	171	136.8	21.13	68.4	478.1

NOMINAL FREQUENCY IS 18 GHz

REFLECTOR WEIGHT = $0.7A_R$ POUNDS, WHERE A_R IS THE REFLECTOR AREA IN SQUARE FEET

BOOM AND STRUCTURE WEIGHT = $3.37\ D_R$ POUNDS, WHERE D_R IS THE REFLECTOR DIAMETER IN FEET

POWER HINGE WEIGHT = $0.1\ A_R$ POUNDS

SWITCH WEIGHT = 0.8 POUNDS x NO. OF SWITCHES

FEEDHORN WEIGHT = $0.03\ N_F$ WHERE N_F IS THE NUMBER OF FEED HORNS

CONTROL PROCESSOR POWER = 0.4 WATTS/SWITCH

FEED PLATFORM WEIGHT = $15 + 0.1\ N_F$ POUNDS. WAVEGUIDE WEIGHT = $0.86\ N_F$ POUNDS (10 FT LENGTHS)

ANTENNA WEIGHT, $W_A = N_F\ (0.1 + 0.03 + 0.86 + 0.118) + A_R\ (0.7 + 0.1) + 3.37\ D_R + 15 + 0.8\ N_{SW}$

W_A (18 GHz) = $1.11\ N_F + 0.8\ A_R + 3.37\ D_R + 15 + 0.8\ N_{SW}$

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A summary of the payload weight and power equations is contained in Table 4.1-53. Figure 4.1-35 and shows the sensitivity of weight and power to the aggregate data rate, parametric in the number of beams.

4.2 SPACE SEGMENT DESCRIPTION

4.2.1 REQUIREMENTS AND CHARACTERISTICS

The CPS System spacecraft configuration is dictated primarily by the geosynchronous operating orbit requirements, and size and weight by the payload equipment and mission life. A typical CPS spacecraft has been synthesized for a 6.2 Kw, 2540 pound payload with an operational life of ten years. An eclipse payload power of 15% (927 watts) has been assumed. Schwarzschild dual reflector antennas having a 115 inch diameter aperture for the transmit antenna and a 92 inch diameter for receive are also assumed.

The high power levels for the S/C (2 to 10 Kw), payload weight and large antenna systems will require launch by the STS using the SSUS-A for lower weight and power payloads and the IUS for the heavier, higher power systems. The IUS has projected geosynchronous injection capabilities of 5000 to almost 10,000 pounds as shown in Table 4.2-1. It will most likely be required for all but the lowest weight and power levels.

The spacecraft on orbit will be a zero momentum three-axis stabilized design using momentum wheels and a reaction-control subsystem (RCS) for attitude control. The Attitude Control Subsystem (ACS) will utilize earth and sun sensors for attitude sensing, and a monopulse antenna for precision pointing capability. A bi-propellant RCS will be used to provide the lowest weight for the large CPS spacecraft.

A symmetrical spacecraft configuration for the geosynchronous orbit is needed to reduce external torques and products of inertia to minimize the ACS wheel size and RcS propellant weight. The CPS system spacecraft concept will use a symmetrical two wing solar array oriented North and South, and will provide a balanced antenna arrangement on the East and West sides of the spacecraft. A single-axis solar array drive will make one revolution per day to keep the array panels normal to the sun.

Table 4.1-53. Summary Of Weight And Power Equations For The TDMA Scanner Processor System

Item	Quantity	Total Weight (Pounds)	Total Power (Watts)
Receive Antenna	1/Payload	$.87\ N_B + .8\ A_R + 3.37\ D_R + 15$	$0.75\ N_B$
Receiver and Second D/C	1/Beam	$0.68\ N_B$	$0.45\ N_B$
Third D/C & IF Amplifier	1/Channel	$0.68\ N_{ch}$*	$0.45\ N_{ch}$
Scanning Beam Switch 46 beam system 68 beam system 100 beam system *where N_{CH} - term in brackets	The number of X Points 42 [(Dr/5000)x20]* 64 [(DR/5000)x24]* 94[DR/5000)x27]*	1.25×10^{-3} x No. of Cross Points	1.4×10^{-2} watts x no. of cross points
Baseband Processor	1/Payload	0.073 Pounds x D_R Mbps	0.235 Watts x D_R Mbps
Upconverter & Driver Assembly	$N_{FB} + N_{SB}$ N_{FB}= No. Fixed Beams N_{SB}= No. Scanning Beams	$0.98\ (N_{FB} + N_{SB})$	$0.7\ (N_{FB} + N_{SB})$
Control and Signalling	1	4	4
Local Oscillators	See Table 4.1.4-11	$11.0 + 0.0018\ D_R + 0.278\ N_B$	$34.3 + 0.0004\ D_R + 0.196\ N_B$
TWTA	$N_{FB} + N_{SB}$	$0.106\ W_{RF} + 6\ (N_{FB} + N_{SB})$	$2.5\ W_{RF}$
Transmitter Ouptut Assemblies	1/Active Beam	$1.68\ (N_{FB} + N_{SB})$	--
Transmit Anenna	1	$1.11\ N_F + 0.8\ A_R + 3.37\ Dia_R + 15 + 0.8N_{SW}$	0.4 watts x N_{SW}
The number of switches is defined in Table 4.1.4-9			
SUBTOTALS			
Harness (2%)			
Brackets, Boxes (1%)			
Low voltage Power supply (1%)			
Contingency (10%)			
TOTAL			

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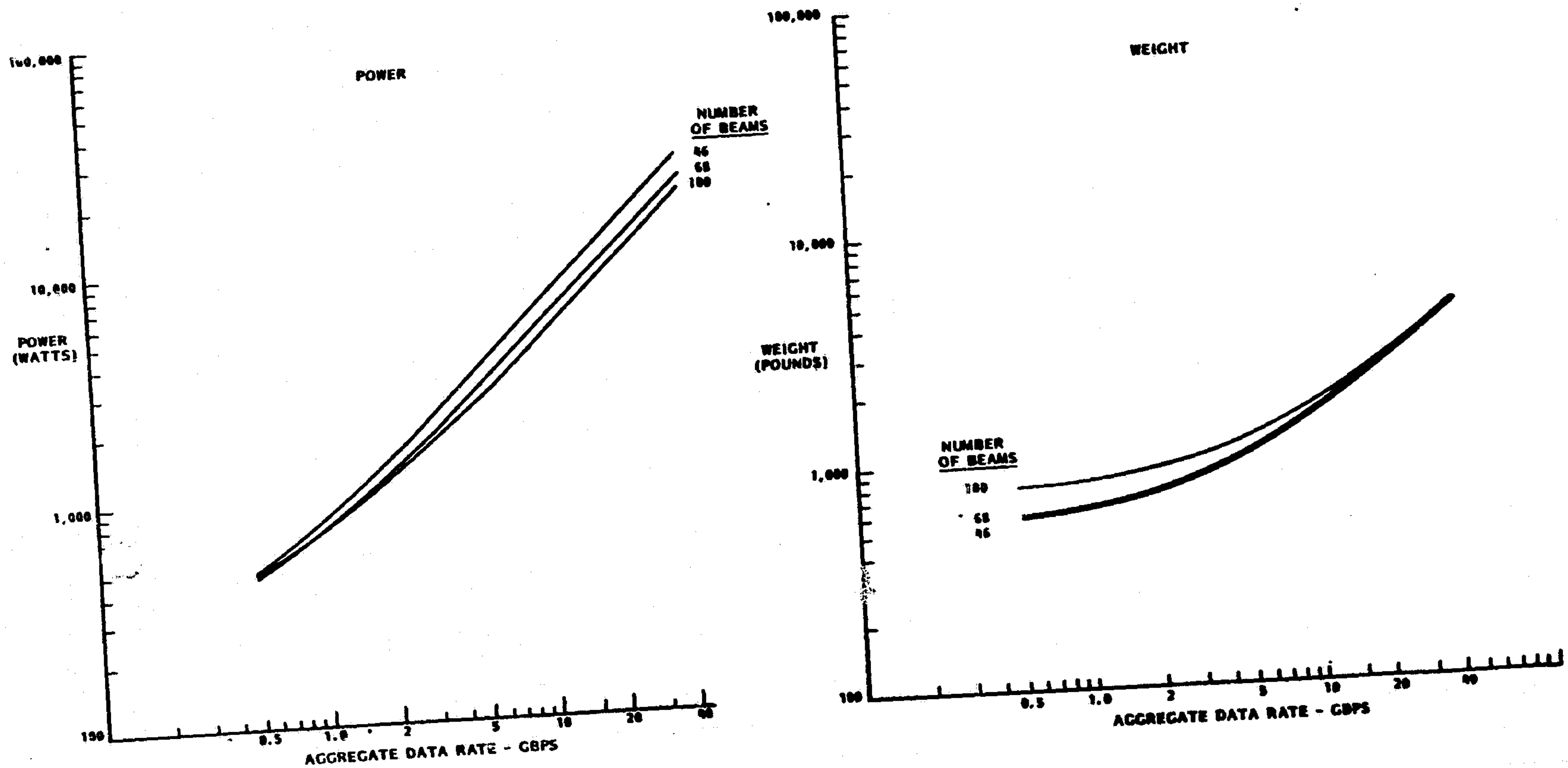

Figure 4.1-35. SS-TDMA/Scanning Beam System Payload Weight and Power Summary

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Table 4.2-1. IUS Growth Options*
(Boeing 1981 Data)

IUS Option No.	10 C Year	Geosynchronous Payload Capability (Pounds)	
1	1985	5381	
2A	1985	5738	Modification and Improvements with existing ASC
2B	1986	5855	
3	1986	6847	
4	1987	9634	Major Redesign New ASE

*Proposed IUS Modification

The Electrical Power Subsystem (EPS) utilizes the MBB type frame-membrane solar array panels currently under development. This array design appears most efficient in the CPS 2 to 10 Kw power range and has been configured using the 1 meter by 3 meter MBB panels. Nickel-hydrogen batteries have shown a significant weight reduction and improved depth of discharge capability over nickel-cadmium batteries, and have been used for CPS power storage.

The CPS system spacecraft characteristics are summarized in Table 4.2-2. In addition to the payload and subsystems previously discussed, the spacecraft features a modular arrangement to facilitate payload and subsystems assembly and test. The selected concept also will limit antenna deployments to the passive reflectors, resulting in a fixed feed and waveguide installation to minimize antenna misalignment and reduce complexity.

C-6

Table 4.2-2. CPS System Spacecraft Characteristics

- STS/IUS Launch Vehicle
  - 5000 to 9600 lb Geosynchronous Capability
- 3 Axis Stabilization and Control
  - Earth Sensors and Monopulse
  - Bi-Propellant RCS (10 Years Orbital Life)
  - Momentum WHeels
- Configuration
  - Symmetrical Two Wing Solar Array
  - Modular Arrangement
  - Deployable Antenna Reflectors
- Communications Payload
  - 115" Aperture Transmit Antenna
  - 92" Aperture Receive Antenna
  - Multiple TWTA Transponder with Redundancy
  - Payload Power, 6180 Watts (Day), 927 Watts (Night)
- Electrical Power
  - MBB Type Frame-Membrane Solar Array (6.6 KW EOL 10 Years)
  - Nickel Hydrogen Batteries (2-32 Cell, 100 AH Total Capability)

4.2.2 LAUNCH CONFIGURATION

The CPS spacecraft configured for launch by the STS/IUS launch vehicle is shown on Figure 4.2-1. The spacecraft body has been sized to provide sufficient mounting and North-South radiator areas for the payload and housekeeping subsystem components, and internal volume for the RCS bi-propellant tankage. The transmit and receive antenna reflectors fold forward along the body "East" and "West" faces and the folded solar array panels are attached over the North and South mounting/radiator panels. The transmit and antenna sub-reflectors and feeds and TT&C antennas are supported by a fixed truss attached to the upper (earth facing) bulkhead. As shown, the overall stowed IUS and spacecraft length is approximately 40 feet, or 2/3 of the 60 foot STS cargo bay length.

4.2.3 ORBITAL CONFIGURATION

The CPS orbital configuration is illustrated on Figure 4.2-1, with the antenna reflectors and solar array fully deployed, and the spacecraft oriented with the array wings and radiators positioned North and South. The antennas, ACS sensors and primary TT&C antenna are earth pointing with the transmit antenna on the East side of the spacecraft and receive on the West.

A central "Bus" section houses the spacecraft housekeeping subsystems and RCS tanks and large upper and lower payload sections with modular panels are provided for the communications payload equipment.

The large solar array has a total span of 112 feet and a panel area of 836 square feet. The 1 meter x 3 meter array panels are positioned outboard to preclude solar cell shadowning by the folding yoke sections and an empty inboard panel frame. The large flexible solar arrays required for high power geosynchronous satellites create increased low frequency perturbations to the spacecraft control system, partacularly for close tolerance pointing such as required for CPS. The selected MBB type frame-membrane two wing array exhibits superior stiffness/weight over both conventional rigid sandwich panels and roll-up or folded embranes in the CPS 2 to 10 Kw power range.

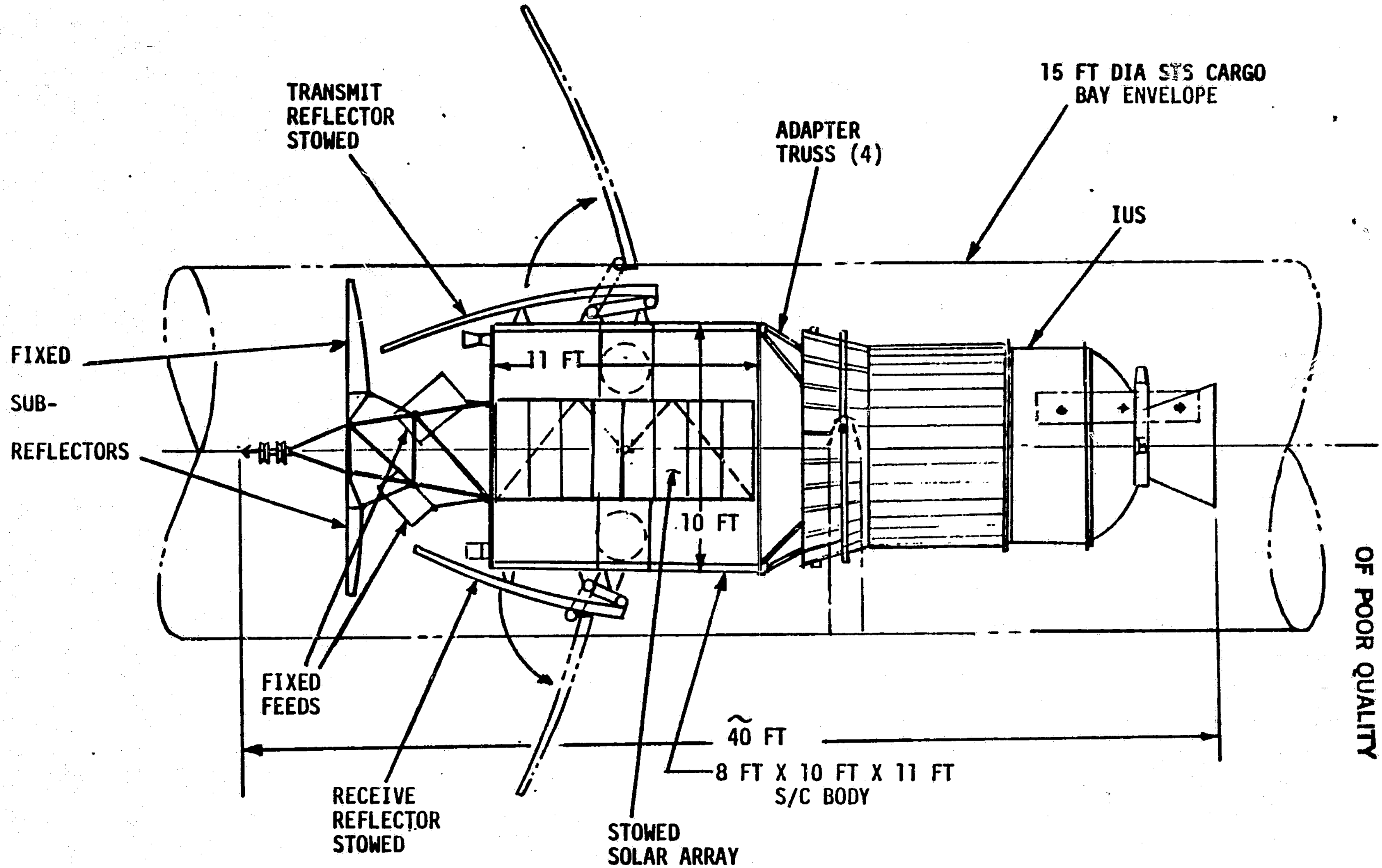

Figure 4.2-1. CPS System Spacecraft Concept (Launch Configuration)

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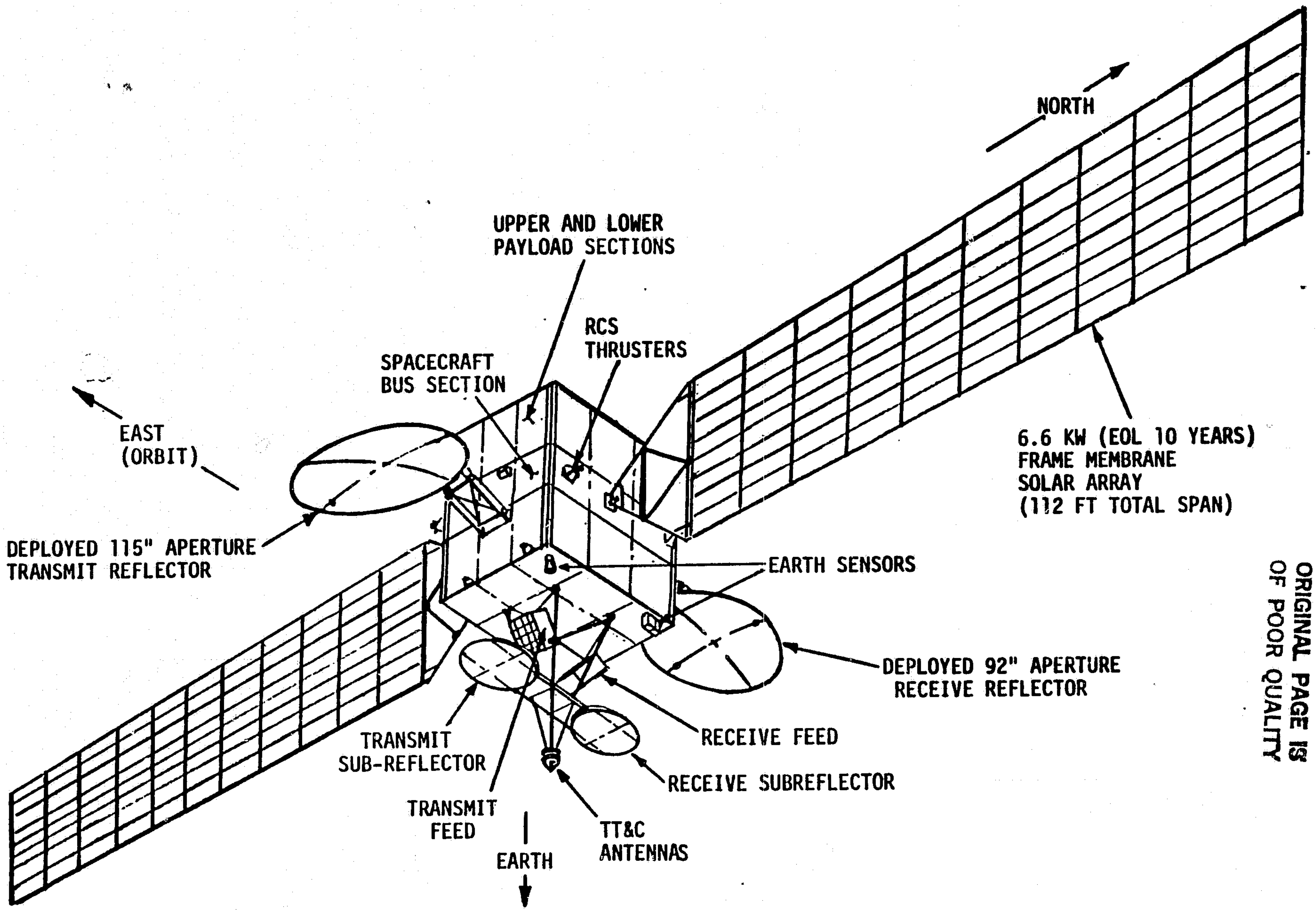

Figure 4.2-2. CPS System Spacecraft Concept
(Orbital Configuration)

4.2.4 SPACECRAFT SUBSYSTEMS AND WEIGHT SUMMARY

4.2.4.1 Structure

The spacecraft body structure is a modular box section 8x10x11 feet high. The primary load path consists of four corner longerons attached via separation nuts to four bi-pod truss assemblies interfacing with the IUS forward builhead. Internal keels, the exterior East and West side panels and four lateral bulkheads are of graphite epoxy faced aluminum honeycomb core sandwich construction, and the North and South mounting/radiator panels are of conventional aluminum honeycomb construction with integral heat pipes for thermal control. Graphite-epoxy struts such as used on DSCS III are employed extensively for tank and internal equipment supports and for the feed and sub-reflector support tower.

The North and South panels are sized to provide over 3000 watts heat dissipation and 200 square feet of mounting surface for payload and housekeeping components.

Structural weight, estimated at 855 pounds including the four bi-pod truss assemblies, is 12.5% of the spacecraft BOM weight, comparable to the BSE/BS-2 and DSCS III BOM weight ratios.

Thermal Control Subsystem (TCS)

Spacecraft thermal control is maintained by multi-layer insulation covering all exposed non-radiating surfaces and Optical Solar Reflector (OSR) coated radiators. Heat pipes will be required for the payload panels in selected areas to distribute high local heat loads into the mounting radiator panels, and guard heaters are used on propellant tanks, sensors and other temperature sensitive components to limit low temperature extremes. CPS thermal control equipment weight has been estimated by comparison to BSE/BS-2 weights scaled-up for the larger, higher dissipation CPS spacecraft. The TCS weight of 200 pounds is 2.9% of the spacecraft 30M weight.

Attitude Control Subsystem (ACS)

Attitude control for CPS is achieved by redundant earth sensors and a precision monopulse antenna providing reference data to a central Attitude Control Electronics (ACE) which generates control signals to four skewed momentum wheels. The CPS ACS is derived from the BSE/BS-2 and DSCS III zero

momentum attitude control subsystms, incorporating larger momentum wheels and a lighter weight Hybrid/LSI ACE design having increased computational capability. Weight of the CPS ACS subsystem is 112 pounds including 63 pounds for the momentum wheels, 21 pounds for the ACE, and 28 pounds for sensors. A celestial sensor ACS reference system was considered for CPS initially, but was replaced by the lighter weight, loss complex monopulse sensor.

Reaction Control Subsystem (RCS)

The RCS is a bi-propellant system using monomethyl hydrazine fuel (MMH) and nitrogen tetroxide (N_2O_4) oxidizer. This type bi-propellant RCS is operating in orbit on Insat, and is currently being fabricated for Intelsat VI. The Bi-propellant RCS has approximately 20% lower weight than all hydrazine RCS due to a 27% higher I_{sp} but higher tankage weight for the bi-propellant system. The estimated weight for the dry RCS is 150 pounds and propellant weight for a BOM spacecraft weight of 6800 pounds, is 1420 pounds. The propellant weight is for a 10 year orbital life with North-South and East-West stationkeeping in addition to spacecraft control functions.

Telemetry, Tracking and Command (TT&C)

The CPS TT&C subsystem provides a redundant primary K-band TT&C capability, and a back-up S-band system for emergency use. The 60 pound CPS TT&C weight estimate includes components, antennas and interconnecting cabling and waveguide.

Electrical Power Subsystem (EPS)

The 6.6 Kw electrical power subsystem is a major drives for both the spacecrafat configuration and weight. The selected EPS utilizes the MBB developed Ultra Light Panel (ULP) solar array design and weight efficient nickel-hydrogen batteries to accomodate the 1.2 Kw eclipse load. The array design and weight have been based on MBB data for the structure and retention and deployment mechanisms, and the General Electric solar array drive used on DSCS III. The solar cell assemblies are 2 mil thick cells with 4 mil gloss covers. This design using the 1 meter x 3 meter MBB panels shows a significantly higher stiffness to weight ratio over rigid sandwich panels, and should be superior to two using roll-up or fold-up membrane-span arrays in the CPS 2 to 10 Kw power range.

The total EPS weight of 936 pounds includes power conditioning components, the nickel-hydrogen batteries and the spacecraft electrical harness segments in addition to the solar array assembly. Estimated total EPS weight variation at lower and higher power levels was 370 pounds at 2 Kw and 1380 pounds at 10 Kw. Specific power variation was 5.4 watts/pound at 2 Kw and 7,2 watts/pound at 10 Kw. The reference 6.6 Kw EPS at 936 pouhds has a specific power of 7.1 watts/pound.

Weight Summary

Payload and subsystem weights for the 6.6 Kw CPS reference spacecraft design are summarized in Table 4.2-3. Total spacecraft weight at launch is 6273 pounds including a 10 year life bi-propellant weight of 1420 pounds. Weight margin for this configuration launched by the STS/IUS Option 3 proposed for 1986, is +574 pounds, 11.8% of the spacecraft dry weight of 4853 pounds. A weight margin of 10% or greater is considered adequate to accomodate normal weight growth during the spacecraft design and development cycle.

Table 4.2-3. CPS System Spacecraft Weight Summary

Subsystem	Weight	
	Pounds	KG
Communications	(2540)	(1151.9)
Antennas	507	229.9
Transponders	2033	922.0
Attitude Control	(112)	(50.8)
Thermal Control	(200)	(90.7)
TT&C	(60)	(27.2)
Electrical Power	(936)	(424.4)
Solar Array	375	170.0
Components	216	98.0
Batteries	180	81.6
Harness	165	74.8
Structure	(855)	(387.7)
Spacecraft	806	365.5
Adapter Truss	49	22.2
Bi-Propellant RCS (Dry)	(150)	(68.0)
Spacecraft (Dry)	4853	2200.9
RCS Bi-Propellant (10 Years)	1420	644.0
Total S/C at Launch	6273	2844.9
Launch Capability	6847	3105.2 STS/IUS Option 3 (1986)
Weight Margin	+ 574	+260.3 11.8% S/C Dry Weight

4.2.5 SPACE SEGMENT COSTS

The approach used to establish space segment costs is based on the Unmanned Spacecraft Cost Model, (SAMSO), Fifth Edition, January 1981. This model is based on an examination of a large spacecraft cost data base. Modifications to the basic model (to include considerations of technology carryover, which emphasizes more recent programs and experience, and technology complexity, particularly three axis high powered spacecraft and complex antenna and transponder arrangements), are necessary to develop representative cost predictions. It is believed that the model as used provides an accurate cost prediction for future KaBand communication satellites of various designs and capacities, measured in constant 1980 dollars. Use of the model has the further advantage that it represents an industry opinion, not the opinion of individuals or an individual company so that it is unbiased with regard to satellite design type, weight or capacity.

The underlying method of the SAMSO model relates cost to subsystem weight (there are some exceptions), providing a method for determining space segment charges vs. satellite capacity. In the analyses the assumption is made (and it is a key one) that the KaBand and related technology has been previously developed so that the nonrecurring costs include principally design type activities and not technology development, e.g. the KaBand satellite is assumed to be state of the art. Consequently its cost, measured in constant 1980 dollars will be similar to current experience except for increases in complexity (and cost) over present designs due to multiple beam antennas, on board processing and switching, more transponders, higher power, etc. This enables development of "first" or acquisition nonrecurring and recurring costs for satellites, related services, launchers, TT&C etc. as a function of satellite weight. The Fifth edition SAMSO Model also includes: Technology Index relatable to experience. Consequently the 1980 cost of a 1990 satellite design is reduced by this factor.

These "first costs" can be converted to a user annual cost by considering depreciation, payback expenses, taxes and satellite "fill" parametrically with regard to the number of preassigned T1 channels. The channel space segment trunk charge is then the annual space segment cost divided by the number of preassigned T1 channels. The methodology for determining space segment service costs is given in section 6.1.

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SAMSO Spacecraft Model

A typical weight distribution for a seven year life 3 axis telecommunications satellite with a power capability of 1200 watts BOL is given in Table 4.2-4, (based on Anik-C design), and Table 4.2-5.

Table 4.2-4. Typical 3 Axis Telecommunication Satelite Weight Distribution, 7 Years Life, 1200 Watts BOL

Communications	164.0 lbs
TT & C	27.7
ACS	57.7
SPS	43.8
Power	358.0
Structure	136.0
TCS	67.9
Ballast & ESD	13.0
AKM Casing	60.3
SPS Fuel	240.4
AKM Fuel	1072.9
Attach Fitting	149.0
S/C & Fitting	2392.7 lbs.
PAM Throw Weight	2477.0 lbs.
Margin	84.3 lbs.

Table 4.2-5. Conversion of Satellite Weight Model Into SAMSO Categories Including Redistribution of Margin

	Weight	Fraction	Margin Allocation	Total
Communications	164.0 lbs.	.188	15.8	180
TT & C	27.7	.032	2.7	30
ACS-SPS	103.5	.119	10.0	114
Power	358.0	.411	34.6	393
Structural, TCS, etc	216.9	.249	21.0	238
Subtotal	870.1	1.000		955
AKM Casing	60.3			60.3
SPS Fuel	240.4			240.4
Margin	84.3			0
Sat BOL Wt	1255.1 lbs.			1255.7

It is useful to compare the NRC and RC as a function of Z, the total BOL spacecraft weight in synchronous orbit. This facilitates computation of cost as a function of satelite weight. It is assumed that the relative weight distribution is independent of satellite capacity, and since satellite system costs are also functions of power that using representative powers is sufficiently accurate for our purposes. This weight allocation is given in Table 4.2-6.

Table 4.2-6. Typical Spacecraft Weight Distribution vs. Total Spacecraft Weight

S/C Model		Z=1255.7
Communication	180.0 lbs.	.143
TT&C	30.0	.042
ACS-SPS	114.0	.091
Power	393.0	.313
Structure, TCS, etc	238.0	.190
Subtotal	955.0	.761
AKM Casing	60.3	.048
SPS Fuel	240.4	0.19
Margin	0	0
Total	1255.7	1.0Z

Spacecraft costing will be based on BOL spacecraft weight of 1255.7 lbs. using SAMSO Normalized CER factors ("technology carryover" and "complexity of design"), where Z equals spacecraft weight (a variable).

The SAMSO Model includes two approaches, Chapter IV is based on the complete data base available in 1981 which represent only a starting point for generalized unmanned spacecraft design concepts. Use of the model understates satellite costs (after adjustment for inflation) because the data base represents the lower technology applications of the 1960's and 1970's. Instead the "normalized" relationships of Chapter V are used which include two important considerations, (1) Technology carryover and Technology Index (2) and Complexity of design.

Technology carryover is an adjustment to the model to account for experience or learning by engineers, etc. in successive satellite programs. For example, design costs for attitude control are reduced on successive programs (for the same fundamental tasks and for the same equipment, measured in constant dollars). Technology carryover emphasizes more recent experience, and recognizes learning. Inclusion of technology carryover has the effect of further reducing the costs predicted by the model. The Chapter V "normalized" relationships are the ones used for this study.

The second consideration, "Complexity of design" provides a method for modifying the baseline cost estimating relationships to reflect the use of more complex designs or higher performance than is available in the original data base. These factors, the results of additional interaction with industry

experts are listed in Appendix B (SAMSO Model). Table 4.2-7 is reproduced from Appendix B which shows how the transponder and antenna complexity impact cost (two tables, one accounting for operational frequency and the other to the use of solid state amplifiers are omitted for brevity). The ranking distributes these cost factors on the basis of allocated weight. The factors actually used are noted in Table 4.2-8. The Consumer Price Index (CPI) issued by the U.S. Department of Labor, Bureau of Statistic, published monthly, provides a measure of the average change in price of goods and services and is a well publicized and widely used index to represent inflation. The CPI for the time period of interest is given in Table 4.2-9.

The impact of inflation on the Aerospace industry is slightly different than the CPI and is based on individual company's anticipation of changes in labor and materials, however, CPI will be used in this Study. The final recurring spacecraft costs are given in Table 4.2-10 including cost of AKM, launch and initial on orbit costs and launch insurance. These costs, (SSUS-D and SSUS-A) are representative of present day spacecraft costs because, it is believed, that while the spacecraft considered here represent a higher level of technology and complexity, (the 5000 lb. satellite is beyond present experience) the technology Index (including experience through the 1980's) will tend to reduce these costs. Final nonrecurring spacecraft costs are given in Table 4.2-11 including AGE. These numbers (for SSUS-D and SSUS-A) appear to be too high. A perusal of the SAMSO data base indicates that the majority of the programs are unique, e.g. the design costs pertain only to one program. Present experience with the comsat market indicates that NRC is, in general, recovered over several program "buys", e.g. there are common elements with the Anik C, SBS, Hughes System and Palappa B satellites. Similarly Satcom, G-Sat and Southern Pacific satellites have many common features. Consequently, it will be assumed that only one half the satellite NRC will pertain to one system. Note that construction (finance) costs are included in the SAMSO Model. Launch vehicle and related costs are given in Table 4.2-12. STS costs are obtained from the Space Transportation System Reimbursement Guide (February 1978), in 1980 dollars. Costs for PAM and insurance are GE estimates. A finance charge is added because this is not included in the STS or PAM costs.

Table 4.2-7. Operational Criteria (From Appendix B of Samso Model, Communications, Table B-4)

OPERATIONAL CRITERIA	DESCRIPTIONS/PARAMETERS	DEGREE OF COMPLEXITY TO COST IMPACT		RANKING OF SUBSYS OPS CRITERIA	
		RDT&E	PROD	RDT&E	PROD
OPERATIONAL FREQUENCY (MHz) AND TRANSMITTER OUTPUT POWER (WATTS)	SEE TABLES B-4A, B-4B			0.212	0.185
NUMBER OF TRANSMITTERS	1 - 2	1.000	1.000		
	2 - 10	1.400	2.100	0.080	0.083
	OVER 10	2.450	3.260		
BANDWIDTH MODIFICATION METHOD	PHASE SHIFT	1.039	1.020		
	BI-PHASE SHIFT	1.000	1.000	0.059	0.056
	QUAD PHASE SHIFT	1.176	1.100		
	FREQUENCY SHIFT	1.137	1.060		
MULTIPLEXING	TIME DIVISION				
	1. NORMAL	1.280	1.100		
	2. MULTIPLE ACCESS	1.675	1.200		
	FREQUENCY DIVISION				
	1. NORMAL	1.000	1.000	0.094	0.112
	2. MULTIPLE ACCESS	1.250	1.050		
	CODE DIVISION				
	1. NORMAL	1.425	1.100		
	2. MULTIPLE ACCESS	2.050	1.225		
REDUNDANCY OF COMMUNICATION	NON-REDUNDANT	1.000	1.000		
	SINGLE REDUNDANCY	1.330	1.390	0.060	0.069
	MORE THAN SINGLE REDUNDANCE	2.020	1.667		
TYPES OF ANTENNA	OMNI	1.000	1.000		
	EARTH COVERAGE				
	1. 0 - 10 dBS (GAIN)	1.700	1.640		
	2. 11 - 20 dBS (GAIN)	2.460	2.080	0.103	0.120
	3. OVER 20 dBS (GAIN)	3.520	2.130		
	SPOT BEAM (NARROW COVERAGE)	3.575	1.488		
	SHAPED BEAM	4.140	1.750		
	MULTI-BEAM	6.860	2.200		

OPERATIONAL CRITERIA	DESCRIPTIONS/PARAMETERS	DEGREE OF COMPLEXITY TO COST IMPACT		RANKING OF SUBSYS OPS CRITERIA	
		RDT&E	PROD	RDT&E	PROD
ANTENNA DESIGN	HORN	1.000	1.000		
	REFLECTOR				
	1. DISH-CENTER FED	1.000	2.271		
	2. DISH-OFFSET FED	2.479	2.479		
	LENS	4.479	5.417		
	HELICAL	1.500	1.352		
	ARRAY			0.175	0.150
	1. SCANNING	5.833	7.313		
	2. PLANAR	3.083	5.208		
	MULTIBEAM				
	1. 0 - 19 PORTS	4.583	4.458		
	2. 20 - 37 PORTS	7.979	7.785		
	3. 38 - 67 PORTS	8.458	8.167		
OPERATIONAL DESIGN LIFE (MONTHS)	0 - 19	1.000	1.000		
	19 - 48	1.125	1.088	0.136	0.144
	49 - 72	1.550	1.188		
	73 +	2.000	1.325		
HARDENING	NATURAL ENVIRONMENT				
	1. SYNCHRONOUS ORBIT	1.000	1.000		
	2. LOW EARTH ORBIT	1.030	1.010		
	NATURAL PLUS NUCLEAR TEST ENVIRONMENT				
	1. SYNCHRONOUS ORBIT	1.190	1.060	0.081	0.081
	2. LOW EARTH ORBIT	1.240	1.080		
	HOSTILE ENVIRONMENT SURVIVE TO				
	1. JSC* REQUIREMENTS X.01	1.230	1.090		
	2. JSC REQUIREMENTS	1.460	1.220		
	3. OVER JCS REQUIREMENTS	2.412	1.475		

* JOINTS CHIEFS OF STAFF

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Table 4.2-8. Complexity, Factor Used in 1981 SAMSO Model

Normalization Factor (Complexity of Design)							
Structure, etc.	Cost NRC	Rank NRC	Impact NRC	Cost RC	Rank RC	Impact RC	Technology Index(1990) NRC RC
Structure MTL, Composition	1.25	.13	.163	1.25	.16	.200	
Shape	1.30	.12	.156	1.30	.12	.156	.872 .878
Thermal Control	1.22	.19	.232	1.27	.18	.229	
Stabilization	1.09	.21	.229	1.10	.24	.264	
Design Life	1.19	.12	.143	1.18	.11	.130	
Hardening	1.07	.10	.107	1.08	.10	.108	
Launch Method	1.20	.13	.156	1.10	.09	.009	
			1:186			1.186	
Composite NRC = 1.186 x .872 = 1,034 Factor RC = 1,1864 .878 = 1,041							
TT&C							
One Board Data Processing	1.08	.17	.184	1.08	.18	.194	.831 .834
Data Handling Rate	1.02	.08	.082	1.03	.08	.082	
Number of Discrete Channels	1.08	.09	.097	1.12	0.1	.112	
Type of Electronics	1.18	.12	.142	1.20	.12	.144	
Encryption Level	1.0	.04	.040	1.0	.04	.040	
Degree of Autonomy	1.0	.09	.090	1.0	.09	.090	
Type of Memory	1.09	.08	.087	1.19	.09	.107	
Design Life	1.46	.17	.248	1.42	.16	.227	
Hardening	1.05	.16	.168	1.05	.14	.147	
			1.138			1.143	
Composite Factors NRC = 1.138 x .831 = .946 RC = 1.143 x .834 = .953							

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Table 4.2-8. Complexity, Factor Used in 1981 SAMSO Model (Cont.)

Normalization Factor (Complexity of Design)							
Structure, etc.	Cost NRC	Rank NRC	Impact NRC	Cost RC	Rank RC	Impact RC	Technology Index(1990) NRC RC
Communications Antenna	1.25	.10	.175	1.85	.08	.148	
Operational Fregoing	1.75	.10	.175	1.85	.08	.148	
No Transmitters	140	.05	.088	1.37	.05	.069	
Modulation	1.12	.02	.022	1.12	.02	.022	
MUX	1.30	.05	.065	1.2	.05	.060	.884 .873
Redundancy	1.36	.03	.041	1.30	.03	.039	
On Board Processing	1.50	.16	.240	1.40	.16	.224	
Data Rate	1.20	.03	.036	1.18	.03	.035	
BER	1.03	.03	.031	1.03	.02	.021	
Encription Level	1.0	.03	.030	1.0	.03	.030	
Type of Antenna	5.44	.08	.435	5.4	.09	.486	
Antenna Design	7.93	.11	.872	8.03	.10	.803	
Power Handling	1.33	.03	.040	1.33	.03	.040	
AJ Capabiluty	1.0	.07	.07	1.0	.07	.07	
Design Life	1.3	.09	.117	1.3	.11	.143	
Hardening	1.08	.12	.130 2.392	1.08	.12	.130 2.32	
Complexity Factor			NRC = 2.392X .884 = 2.115 RC = 2.32 x .873 = 2.03				

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Table 4.2-8. Complexity, Factor Used in 1981 SAMSO Model (Cont.)

Normalization Factor (Complexity of Design)							
Structure, etc.	Cost NRC	Rank NRC	Impact NRC	Cost RC	Rank RC	Impact RC	Technology Index(1990) NRC RC
ACS Attitude Control	1.0	.21	.21	1.0	.22	.22	
Station Keeping	1.0	.25	.25	1.0	.25	.25	
Pointing Accoracy	1.18	.23	.271	1.18	.21	.248	.876 .840
Stabilization	1.23	.13	.160	1.19	.11	.131	
Design Life	1.28	.12	.154	1.20	.14	.168	
Hardening	1.0	.06	.06 1.105	1.0	.07	.07 1.087	
Composite Factor NRC = 1.105 x .876 = .968 RC = 1.087 x .840 = .913							
EPS Design Type	1.25	.22	.275	1.39	.19	.264	
Mechanical Interface	1.14	.14	.160	1.11	.13	.144	
Powers	1.45	.24	.348	4.63	.21	.972	.876 .900
Batteries	1.43	.14	.200	1.44	.16	.230	
Design Life	1.22	.15	.183	1.16	.20	.232	
Hardening	1.0	.11	.11 1.276	1.01	.11	.111 1.953	
Composite Factor NRC = 1.276 x .840 = 1.072 RC = 1.953 x .900 = 1.758							

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Table 4.2-9. CPI for Period of Interest

	CPT 1967 Base	Annual Rate
1977	181.5	6.5%
1978	195.4	7.7
1979	217.4	11.3
1980	246.8	13.5

Table 4.2-10. Recurring Costs in 1980 Dollars, Computed by SAMSO Model for Three Representative Spacecraft Modules

Item	Complexity Factor and Index	Normalized Cost Relationship	Inflation Factor	Cost Relationship	Cost 1980 Dollars (K$) 1250/1250	2500/2500	5000/5000
Structure	1.04	$19.38\ x^{.66}$	1.12	$7.55Z^{.66}$	835	1320	2086
TT&C	.953	$14.11 + 33.04x^{.91}$	1.12	$15.0 + 1.97Z^{.97}$	1311	2451	4591
Communication/	2.030	$41.02X^{.87}$	1.12	$17.1Z^{.87}$	8459	15460	28255
ACS-SPS	.913	$21.40X^{.97}$	1.12	$2.14Z^{.97}$	2160	4231	8287
EPS	1.758	$72.4(XP)^{.27}$*	1.12	$104.2PZ^{.27}$*	5260	7648	11119
Program Level Factor	3.291				5934	10238	17981
S/C RC, 1980 Dollars					23964	41348	72619
AKM Cost (Estimate)					800	900	1000
Launch/On orbit Cost					525	555	555
Subtotal					25319	42803	74174
Launch Insurance (@ 8%)					2026	3424	4934
Total Recurring cost, 1980 Dollars					27345	46227	80108

* P = BOL Power

Table 4.2-11. Nonrecurring Costs in 1980 Dollars, Computed by SAMSO Model for Three Representative Spacecraft Models

ITEM	COMPLEXITY FACTOR	NORMALIZED COST RELATIONSHIP	COST RELATIONSHIP*	Cost 1980 Dollars ($1000) 1250/1250	2550/2500	5000/5000
Structure	1.034	$1098.18 + 90.99\ X^{.67}$	$1135.5 + 30.92\ Z^{.67}$	4810	6982	10437
TT&C	.946	$705.23 + 34.8\ X$	$667.1 + .790Z$	1655	2642	4617
Communications/Ant	2.115	$1468.67\ X^{.57}$	$327Z^{.57}$	19045	20773	41972
ACS-SPS	.968	$833.61 + 60.3X$	$806 + 5.31Z$			
EPS	1.072	$2098.95 + .0340(PX)^{.93}$	$2520 + .013(PZ)^{.93}$	12735	18010	25470
Subtotal				45689	69989	109853
AGE				7000	11000	15000
Program Level Factor	.3568			16302	24972	39196
Total NCR (S/C Only)		(1980 Dollars)		68991	105961	164049

* Inflation Factor 1.12

P = B.O.L. Power

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Table 4.2-12. Launch Vehicle Cost Characteristics, Thousands of 1980 Dollars

SPACECRAFT WEIGHT, BOL, LBS	1,250	2,500	5,000
SHUTTLE TRANSPORTATION SYSTEM (STS) COST	$ 8,000	$16,000	$32,000
PERIGEE ASSIST MOTOR (PAM) COST	5,000	7,000	10,000
SUBTOTAL	$13,000	$23,000	$42,000
ON-ORBIT INSURANCE *	6,500	11,500	21,000
LAUNCH INSURANCE (@ 8%) *	1,040	1,840	3,360
SUBTOTAL	$20,540	$36,340	$66,360
FINANCE COST (3 YEARS @ 10%)	3,595	6,360	11,613
TOTAL LAUNCH COST	$24,135	$42,700	$77,973

* ESTIMATED BY THE PRESENT VALUE AT TIME OF LAUNCH AT 10% INTEREST OF THE PRODUCT OF THE CUMULATIVE PROBABILITY OF FAILURE TIMES THE PRESENT VALUE OF AN ADDITIONAL LAUNCH VEHICLE (A SPARE "GROUND" SATELLITE COST IS ALREADY INCLUDED)

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The foregoing costs are displayed in Figure 4.2-3 as a function of spacecraft BOL weight. Cost of AKM, launch and launch insurance are added to spacecraft RC to obtain the "total recurring cost" in Figure 4.2-3. Similarly insurance and finance costs are added to launch vehicle cost to obtain the "total launch cost".

This information can be added to find the lump sum space segment investment at the beginning of satellite life, e.g. t=0. The system consists of two orbiting satellites (one a spare), two launch vehicles plus a satellite ground spare. Insurance is sufficient to permit one additional launch over the system life time (to counter a launch failure or satellite on orbit failure), therefore the cost represents a scenario somewhere between the "best" and "worst".

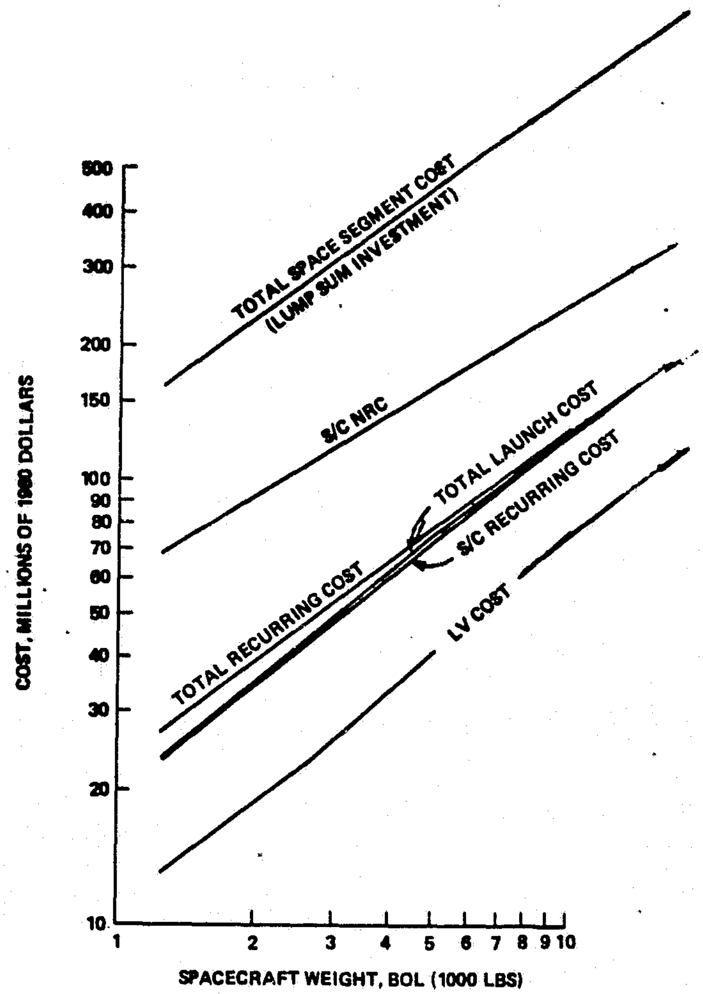

Figure 4.2-3. Space Segment Lump Sum Investment

The annual space segment change over the lifetime of the system (over the system lifetime all costs are incurred and salvage at end of life is zero), is obtained by converting the lump sum investment at t=0 into an annual charge that considers return on investment, payback, expense, depreciation and taxes, to be defrayed against a satellite with a specified trunk capacity and a satellite "fill", e.g. the satellite is assumed to be fully loaded only during the busy hour of the last year of operation. The conversion of investment to annual charge is described below.

The approach to determine annual charges is based on a system with payback that increases with system useage. The payback on initial investment increases with year, which is the case for the CPS satellite traffic (varies from about 10% capacity in 1990 to about 90% capacity in the year 2000). For an initial investment "R", it is assumed that the payback "P" varies as A $(1 + r)^t$ for an annual growth rate of r (t = time in years). For a satellite life of T_o years, the residual value of investment should equal zero and

$$\frac{R}{A} = \frac{1}{X} = \sum_{K=1}^{T_o} \left(\frac{1+r}{1+s}\right)^K$$

where i = return on investment

The term R/A can be solved from above summation. Defining the quantity x = A/R, the total payback P in terms of initial investment R

$$= \int_0^{T_o} A\,(1+r)^t = \frac{XR}{\text{Ln}(1+r)} \quad [(1+r)^{T_o} - 1]$$

To determine annual charges, the capacity is assume to vary with the above fixed annual growth rate r such that for an aggregate maximum capacity C (which occurs at end of life), the capacity is an any time t equal to:

$$C \quad \frac{(1+r)^t}{(1+r)^{T_o}}$$

For a annual service charge of Cu, the total yearly charges assumed proportional to capacity C are:

$$C_u \quad \frac{(1+r)^t}{(1+r)^{T_o}}$$

At the end of life T_o, the annual charge equals Cu, using the relationships that net after tax annual income or payback equals:

P = (annual charges - expenses - taxes)
and
Taxes = TR (annual charges - depreciation - expenses)
where

TR = tax rate
Depreciation = R/T_o
Expenses = KR

The annual service charges at full capacity (at T_o) are:

$$C_u = R \quad \frac{X\left[\frac{(1+r)^{T_o} - 1}{\mathrm{Ln}\,(1+r)}\right] + (1-T_R)\,KT_o - T_R}{(1-TR)\left[\frac{(1+r)^{T_o} - 1}{(1+r)^{T_o}\ \mathrm{Ln}\,(1+r)}\right]}$$

For the analysis of annual service costs, the first factor needing determination is the lump sum initial investment R. The initial lump sum investment as function of satellite weight is given in Figure 4.2-1. The system described in Section 4.2 is assumed to consist of two orbiting satellites; one is standby, one ground spare satellite and two launch

vehicles. Insurance is assumed sufficient to permit one additional launch over the system life time incase of failure on launch or in orbit. The initial lump sum investment equals for the above scenario: R = total recurring costs (3 satellites) plus one-half non-recurring costs plus total launch cost for two satellites. The cost elements in Figure 4.2-1 (1980 dollars) are derived from 1981 SAMSO cost model which relates cost to satellite weight, power and complexity.

The cost versus weight of Figure 4.2-3 in equation form is:

$$\text{Ln}, R = 0.7625 \text{ Ln } W + 4.936$$

where

R = Lump sum investment (millions of dollars)
W = Satellite (BOL weight (1000 lbs)

In the determination of satellite weight, it is assumed that the net power system plus communication payload weight is a fixed percentage of satellite weight. For systems of the 1990 - 2000 period, this percentage is between 40 and 45% for the cost model in question, it is assumed that this percentage is 45% and that the satellite weighs 2.22 times the sum of payload and power system weight.

The satellite communication payload weight and power as a function T1 channel EIRP, (system and availability), earth station antenna diameter, number of satellite beams, data rate (capacity), burst rate (TDMA), and system. The payload weight and power are expressed in analytic form in Tables 4.2-13 to 4.2-16 for the SS-FDMA, SS-TDMA Fixed Beam, HYBRID, and the SS-TDMA/Scanning Beam systems. These expressions are based on the data given in Section 4.1.

The EIRP can be derived from the data presented in Tables 3.2-18 and 3.2-19 for the cases of non-diversity and diversity. The data given in Tables 3.2-18 and 3.2-19 is that for a given rain zone vs availability at a data rate of 1.544 Mbps for a one meter diameter earth station antenna. To obtain satellite EIRP over CONUS, the data of Tables 3.2-18 and 3.2-19 must be averaged with respect to the relative traffic in each rain zone. From the satellite beam traffic data maps, the relative traffic in zones C (B,F), D, and E are respectively 20%, 68% and 12%. The satellite EIRP requirements, based on the above averaging of Table 3.2-18 and 3.2-19 data, is given in

Table 4.2-17. Four cases are considered in Table 4.5-17; no diversity, diversity, diversity in rain zone E only, and diversity in zones D and E (with no diversity in Zone C(B,F). The algorithms presented in Tables 4.2-13 through 4.2-16 utilize the 1.544 Mbps EIRP presented in Table 4.2-17 and compute the satellite EIRP by increasing the EIRP in terms of satellite data rate (capacity) C by 10 $\log_{10}C/1.544$ and reducing the EIRP by the earth station antenna gain by 20 $\log_{10}D$.

The power system weight can be obtained from the payload power by multiplication by a factor which represents power system specific weight. For the period in question (year 1990 - 2000), it is assumed advanced lightweight solar cells and nickel - hydrogen battery technology is used with a specific weight of 50 pounds per kilowatt. However, both weight and power are increased by ten percent for contingency.

The effect of parameters on overall cost is presented in section 7.0. However, two major factors are apparent. First, the weight and, hence, cost is very sensitive to EIRP which in turn depends strongly on availability. For the case of no diversity, increasing the availability from 99.5% to 99.9% increases the EIRP by two orders of magnitude. However, if earth station space diversity is utilized, the availability can be increased to more than 99.9% with no penalty in EIRP. If a TDMA system were selected, diversity would be required only in the E zone for only a small increase in EIRP (and cost).

In determination of annual costs, "Fill factor" is significant. If the growth of the satellite traffic varies from 10% of the year 2000 traffic during 1990 to full traffic during the year 2000, the annual charges are about twice that when compared to a system which operates at maximum capacity over the ten year period.

A third significant factor in determination of charges is system capacity. In section 7.0, the systems with greatest capacity are shown to results in the smallest unit service costs.

Table 4.2-13. SS-FDMA Weight & Power Functions

- o Weight (lbs) = $46.6 + 4.94\sqrt{N_B} + 13.38\ N_B + .035\ N_{ch} + 0.14\ N_{sp} + 0.045\ N_{pach} + (EIRP)\ 9.72 \times 10^{-4}\ (DR/N_B)\ (1/D')^2$ + Channelizing Units (Table below)

- o Power Watts = $39 + 4.24\ N_B + .05\ N_{ch} + .03\ N_{sp} + .27\ N_{pach} + (EIRP)\ 5.73 \times 10^{-3}\ (DR/N_B)\ (1/D')^2$ + Channelizing Units (Table below)

where:

N_B = Number of Beams

N_{ch} = number of channels switched

N_{sp} = number of spare channels

N_{pach} = Number of preassigned channels

EIRP = From Table 4.2-17 (in watts)

DR = Data Rate Mbps

D^1 = Earth station antenna diameter, meters

SWITCH MATRIX AND CHANNELIZING UNITS

AGGREGATE DATA RATE	CHANNELS PREASSIGN (N_{pach})	CHANNELS SWITCHED (N_{ch})	CHANNELS SPARES (N_{sp})	WEIGHT* (Channelizing Units)	POWER* (Channelizing Units)
500	2138	46	218	162.7	768.0
1000	2164	54	221	166.3	780.3
2000	2234	66	229	172.5	810.2
5000	2484	173	266	221.7	1035.0
10,000	2693	272	297	264.0	1228.3
15,000	2903	376	328	312.2	1451.0
20,000	3005	409	342	327.2	1518.8
40,000	3305	569	388	401.6	1860.1

*Includes Switched, Spare, and Preassigned channels.

Table 4.2-14. SS-TDMA/Fixed Beam Weight And Power Functions

- Weight (lbs) = $47.6 + 5.01\sqrt{N_B} + 13.38\ N_B + .206\ N_{ch}$ + (EIRP) 9.72×10^{-4} $(DR/N_B)\ (1/D')^2$ + Switch Weight (Table below)
- Power Watts = $42 + 4.24\ N_B + 0.2\ N_{ch}$ + (EIRP) 5.73×10^{-3} $(DR/N_B)\ (1/D')^2$ + Switch Power (Table below)

where: N_B = Number of Beams

N_{ch} = number of channels

N_R = data rate in Mbps

EIRP = From Table 4.2-17 (in watts)

D^1 = Earth station antenna diameter, meters

SUMMARY OF CHANNELS AND SWITCH MATRIX DATA

DATA RATE Mbps	N_{ch} WEIGHT	computing POWER	SWITCH MATRIX WEIGHT	SWITCH MATRIX POWER
500	12	9	4.5	7.0
1000	19	16	5.4	11.6
2000	36	31	7.5	23.8
3000	50	48	11.0	41.0
5000	83	74	15.25	65.8
10,000	164	148	30.83	141.5
15,000	246	222	48.7	229.8
20,000	327	296	68.1	323.8
40,000	653	592	163.4	788.5

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Table 4.2-15. HYBRID System Weight And Power Functions

- Weight (lbs) = $45.2 + 5.04\sqrt{N_B} + 12.94\ N_B + 0.274\ N_{ch} + .1168\ DR + (EIRP)\ 2.43 \times 10^{-4}\ (DR/N_B)\ (1/D')^2$
- Power Watts = $39.3 + 3.0\ N_B + 1.0\ N_{ch} + 0.2584\ DR + (EIRP)\ 5.73 \times 10^{-3}\ (DR/N_B)\ (1/D')^2$

where: N_B = Number of Beams

N_{ch} = Number of channels

D_R = Data rate in Mbps

EIRP = From Table 4.2-17 (in watts)

DATA RATE Mbps	N_{ch} for WEIGHT	N_{ch} for POWER
500	2402	2184
1000	2439	2218
2000	2529	2300
3000	2600	2416
5000	2923	2657
10,000	3262	2965
15,000	3607	3279
20,000	3756	3414
40,000	4262	3874

Table 4.2-16. SS-TDMA (Scanning Beam) Weight And Power Functions

- Weight (lbs) = $45 + 4.94\sqrt{N_B} + 3.645\ N_B + 0.68\ N_{ch} + 1.25 \times 10^{-3}\ N_{cp}{}^{*} + 8.66\ N_B{}' + 0.8\ N_{sw} + .0748\ DR + (EIRP)\ 2.43 \times 10^{-4}\ (DR/N_B)\ (1/D')^2 L'$

- Power (Watts) = $38.3 + 1.396\ N_B + .45\ N_{ch} + .014\ N_{cp} + 0.7\ N_B{}' + 0.4\ N_{sw} + .2354\ DR + (EIRP)\ 5.73 \times 10^{-3}\ (DR/N_B)\ (1/D')^2 L'$

where:

N_B	=	Number of Beams
N_{ch}	=	Number of channels
N_{cp}	=	Number of Crosspoints in Channel Switches
$N_B{}'$	=	Number of active downlink beams at any time
N_{sw}	=	Number of output switches
DR	=	Data Rate in Mbps
EIRP	=	Numerical Value Table 4.2-17
D'	=	Earth Station antenna diameter, meters
L'	=	Added output loss in switching of beams

			Number of Beams		
			46	68	100
N_{ch}	=	Number of Channels	20	24	27
N_{cp}	=	Number of Cross-points in Channel Switches	0.168 DR	0.3072 DR	0.5076 DR
$N_B{}'$	=	Number of Downlink Beams (Active)	9	9	11
N_{sw}	=	Number of Output Switches	41	61	93
L'	=	Added Switch Loss in Output	1.26(1dB)	1.26(1dB)	1.32(1.2dB)

Table 4.2-17. Satellite EIRP Requirements (dBw)

Case	System	Availability		
		99.5%	99.9%	99.95%
NO DIVERSITY ALL ZONES	FDMA	56.07	71.97	101.8
	TDMA (Fixed Beam)	50.50	70.16	95.09
	TDMA (Scanning Beam)	49.22	69.94	92.39
DIVERSITY ALL ZONES	FDMA	50.91	50.91	50.91
	TDMA (Fixed Beam)	50.73	50.73	50.73
	TDMA (Scanning Beam)	49.22	49.22	49.22
DIVERSITY ZONE E ONLY	FDMA	53.64	58.40	66.32
	TDMA (Fixed Beam)	50.73	53.29	59.97
	TDMA (Scanning Beam)	49.22	51.67	58.65
DIVERSITY ZONE E & NO DIVERSITY ZONE C (B, F)	FDMA	51.18	52.14	52.27
	TDMA (Fixed Beam)	50.69	50.69	50.95
	TDMA (Scanning Beam)	49.22	49.28	49.34

- EARTH STATION ANTENNA DIAMETER 1 METER
- DATA RATE 1 Mbps
- TRAFFIC
  Zone C (B, F) 20%
  Zone D 68%
  Zone E 12%

SECTION 5

TASK 4 - DEFINITION OF INTEGRATED SATELLITE SYSTEMS

SECTION 5

TASK 4 - DEFINITION OF INTEGRATED SATELLITE SYSTEMS

As shown in Section 7, Sensitivity Analyses, the use of large earth stations with ground networking and large, high power spacecraft leads to minimum service costs. Consequently, the system features high capacity and high availability. Large capacity, if utilized early in the space segment life, minimizes the service costs. To capture the large market available of 99.9% or greater are required. The system characteristics are summarized in Table 5-1.

The sensitivity analysis indicate that the SS-TDMA access techniques lead to minimum service costs and these are the candidates for servicing the principal markets. A secondary technique that would minimize earth station costs for smaller users and also interface with the primary access techniques is the HYBRID.

A large spacecraft is required to support the required traffic and it would be launched via STS/IUS that is expected to be available when required. The space segment characteristics are summarized in Table 5-2.

The associated ground segment features predominately large earth station with concentration tails in urban areas. The transmission media used for networking interconnects the Earth Station's for space diversity operation and to provide backup for equipment failures. Thereby not only in proving availability as required to capture the large market but eliminating the need for equipment redundancy. The ground segment characteristics are summarized in Table 5-3.

Since early loading of the system is important to minimize service costs, a reasonsable approach to establishing the system is to emphasize capturing the largest users first, particularly those using the services that make use of the unique satellite system characteristics of readily establishing subnetworks and supporting the wideband channels. These are the large businesses, institutions and Government agencies. These users will support the system operation, they have sufficient traffic requirements, and the other users can benefit from the resulting lowered system service costs. This is summarized in Table 5-4.

Table 5-1. Integrated System Description

SYSTEM CHARACTERISTICS	VALUE	COMMENTS
• AGGREGATE CAPACITY	- 10 to 15 GBPS	- LARGE SYSTEM MAKES POSSIBLE ECONOMY OF SCALE NECESSARY TO COMPETE WITH OTHER SYSTEMS - LIMITED BY SYSTEM BANDWITH AVAILABLE - REQUIRES ABOUT 0.3° ANTENNA BEAMWIDTHS - FREQUENCY REUSE IS CRITICAL
• CHANNEL AVAILABILITY	- 99.9%	- NECESSARY TO CAPTURE THE REQUIRED TRAFFIC
• COVERAGE	- FULL CONUS	- SERVICE PROVIDED TO AREAS WITH LIGHT TRAFFIC AS WELL AS URBAN AREAS
• COMMUNICATION SERVICES	- ALL SUPPORTED	- VOICE (41%), VIDEOCONFERENCING (34%) PREDOMINATE

Table 5-2. Space Segment Characteristics

CHARACTERISTICS	DESCRIPTION	COMMENT
• PRINCIPAL ACCESS TECHNIQUE	- SS-TDMA	- EITHER FIXED BEAM (NON-DEMODULATING) OR SCANNING BEAM - FOR SERVICING LARGE EARTH STATIONS
• SECONDARY ACCESS TECHNIQUE	- HYBRID	- REQUIRED TO PROVIDE INTERCONNECT TO PRINCIPAL ACCESS - HYBRID PAYLOAD WEIGHT IS A CONCERN
• SPACECRAFT CLASS	- STS/IUS LAUNCH - 6,320 LBS, 6180 WATTS (927 NITE)	- REQUIRED LAUNCH VEHICLE EXPECTED TO BE AVAILABLE IN LATE '80's
• ATTITUDE CONTROL	- DUAL MONOPULSE - EARTH SENSORS	- RELATIVELY LIGHT WEIGHT AND MONOPULSE PROVIDES MEANS FOR MEASURING ANTENNA REFLECTOR DISTORTION

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Table 5-3. Ground Segment Characteristics

	VALUE	COMMENTS
• LARGE EARTH STATIONS PREDOMINATELY	- 5M to 7M ANTENNAS - 12T1 OR MORE AGGREGATE CAPACITY	- DRIVEN BY SPACE POWER COSTS AND ES RF EQUIPMENT COSTS
• SMALLER EARTH STATIONS FOR STANDALONE APPLICATIONS	- 3M to 5M ANTENNAS - 56 KBPS TO 1T1 CAPACITY	- SERVICE IN AREAS (RURAL) WHERE GROUND NETWORKING NOT PRACTICAL - ACHIEVING LOW ES COST IS SIGNIFICANT PROBLEM
• GROUND NETWORKING IN URBAN AREAS	- 67% OF MARKET BASED ON TRAFFIC GENERATED	- USER DENSITY IS SUFFICIENT TO MAKE GROUND NETWORKING COST EFFECTIVE
• SPATIAL DIVERSITY ES OPERATION	- ES's SERVICING USERS GENERATING 67% OF TRAFFIC	- REDUCES BOTH SPACE AND ES EIRP AND G/T REQUIREMENTS - ES INTERCONNECT INTEGRATED INTO GROUND NETWORKS

Table 5-4. Market Capture

• LARGE BUSINESS	- AS A GROUP, GENERATES MOST OF THE TRAFFIC (55%) - HAS REQUIREMENTS FOR SUBNETWORKS - GOOD CANDIDATE FOR EARLY LOADING OF SYSTEM
• INSTITUTIONS	- AS A GROUP, GENERATE SECOND LARGEST AMOUNT OF TRAFFIC (24%) - CANDIDATE FOR SPECIALIZED SUBNETWORKS - CANDIDATE FOR EARLY LOADING OF SYSTEM
• LARGE GOVERNMENT AGENCIES	- ALTHOUGH SMALLER TRAFFIC GENERATION (7%) GOVERNMENT IS A POTENTIAL SOURCE OF EARLY LOADING
• OTHER	- LOADING BY FIRST CLASSES PROVIDES BASE FOR ESTABLISHING SERVICE COSTS MAKING THE SERVICES ECONOMICAL FOR THESE USERS

SECTION 6

TASK 5 - SERVICE COSTS FOR INTEGRATED SATELLITE SYSTEMS

SECTION 6

TASK 5 - SERVICE COSTS FOR INTEGRATED SATELLITE SYSTEMS

The service costs for the integrated satellite systems are the sum of the contributions of the space segment, ground networking and earth stations cost components. Discussed in this section is the procedure for determining the service costs for the elements of the integrated satellite system and means of accessing charges based on traffic service useage to user group facilities.

6.1 SPACE SEGMENT SERVICE COSTS

The procedure for computation of space segment service costs as a function of aggregate capacity, availability, number of satellite beams over CONUS, earth station antenna diameter, and system is given in Figure 6.1-1. The procedure is to determine payload weight and power from EIRP and system parameters, satellite weight from payload weight and power, lump sum investment from satellite weight, and annual service charges and their distribution from initial investment and financial and market parameters. The above technique is defined in Section 4.2.5.

6.1.2 USER AND TRAFFIC SERVICE CHARGES

The billing of these annual service charges to the different user groups should be based on their relative utilization of the space segment. The relative utilization of the space segment by the different user groups is presented in Tables 2.3-4 and 2.3-5 for respective availabilities of 99.5% and 99.9%. In these tables, a matrix is given of the share of the average hour traffic versus user group and traffic service normalized to a total value of one. The space segment charges per user group for any traffic service equals the total annual service charges times the value given in a corresponding location in Tables 2.3-4 and 2.3-5.

The annual service charges per user facility can be obtained from the value of total annual service charges (described above) divided by the number of user facilities. The number of user facilities versus user group and aggregate traffic/availability is given in Table 2.3-11. The space segment contribution to various traffic service annual charges can be obtained from the charges per facility versus user group and traffic service and the data defining the volume of services versus user facility. These latter data are given in Tables 2.3-9 and 2.3-10 for respective availabilities of 99.5% and 99.9%.

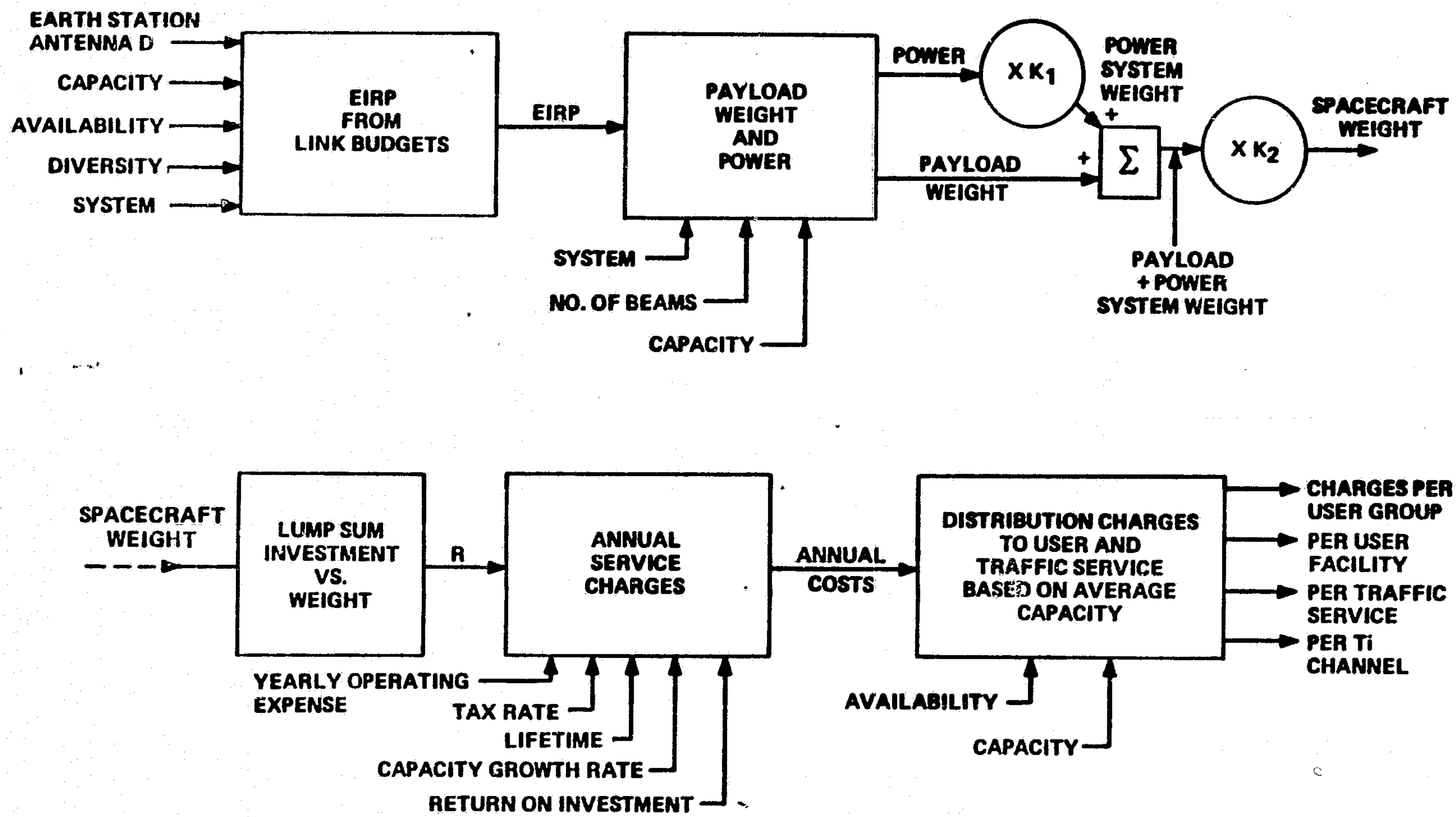

Figure 6.1-1. Space Segment Costs Computation

An example of the utilization of above procedure is illustrated for the following system:

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SS-FDMA System
Capacity = 15 Gbps
Availability = 99.9%
Diversity in all Rain Zones
Number of Satellite Beams = 68
Earth Station Antenna Diameter = 7m

The payload weight on power computed from Section 4.2.5 data are respectively 2185 pounds and 7022 watts which gives a combined power system and payload weight of 2571 pounds and a satellite weight of 5714 pounds. The initial lump sum investment for this weight is 526 million dollars. The annual service charge of the space segment is 622.6 million dollars.

The distribution of these annual space segment charges to the user group and traffic services is presented in Table 6.1-1. The annual service charges per user facility and the further distribution of these charges by traffic service is given respectively in Tables 6.1-2 and 6.1-3.

6.2 GROUND NETWORKING SERVICE CHARGES

The procedure for determining ground networking service charges is summarized in Figure 6.2-1. The major assumption in this procedure is that the

Table 6.1-1. Annual Space Segment Charges vs. Class/Traffic Service ($1M)

AVAILABILITY= 99.9% CU(TOTAL)=622647940.

USER CLASS	VOICE	VIDEO CONF.	VIDEO INFO. SERV.	DATA MESS.	DATA COMPUT.	TOTAL USER
LARGE BUSINESS	163.38	157.65	0.00	8.58	12.25	341.90
SMALL BUSINESS	40.10	0.00	0.00	4.39	3.76	48.25
GOV. AGENCIES	14.54	9.23	18.46	.84	1.43	44.50
MUNICIPALITIES	8.80	0.00	0.00	.96	.83	10.59
INSTITUTIONS	17.22	41.53	83.06	2.26	3.23	147.29
HOMES AND CONDOS	9.96	0.00	19.23	0.00	.30	29.51
TOTAL TRAFFIC SERVICE	254.04	208.40	120.73	17.02	21.80	622.65

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Table 6.1-2. Annual Space Segment Charges Per User Facility ($1000)

USER CLASS	AVAILABILITY= 99.9%
LARGE BUSINESS	278.0
SMALL BUSINESS	25.6
GOV. AGENCIES	618.1
MUNICIPALITIES	25.6
INSTITUTIONS	454.6
HOMES AND CONDOS	393.5

Table 6.1-3. Space Segment Cost Per User Class/Traffic ($1000)

USER CLASS	VOICE	VIDEO CONF.	VIDEO INFO. SERV.	DATA MESS.	DATA COMPUT.	TOTAL USER
LARGE BUSINESS	132.83	128.17	0.00	6.98	9.96	277.96
SMALL BUSINESS	21.25	0.00	0.00	2.32	1.99	25.57
GOV. AGENCIES	201.93	128.16	256.41	11.62	19.92	618.06
MUNICIPALITIES	21.25	0.00	0.00	2.33	1.99	25.57
INSTITUTIONS	53.14	128.18	256.36	6.97	9.96	454.61
HOMES AND CONDOS	132.83	0.00	256.36	0.00	3.98	393.51

coverage areas of each earth station are equal, there is equal shareability of all user facilities, and spacing between facilities are assumed to be uniform in a given region.

In determination of ground network length requirements, facility density is a key parameter. It is a function of urban area and is directly proportional to aggregate peak capacity. Facility density data is presented in Section 2.4.2 and in Table 4.2-22 for different metropolitan areas. As is discussed in Section 2.4.2, and in Section 3.6, an average urban area for a system with a peak aggregate capacity of 5 Gbps, has a facility density of 0.024

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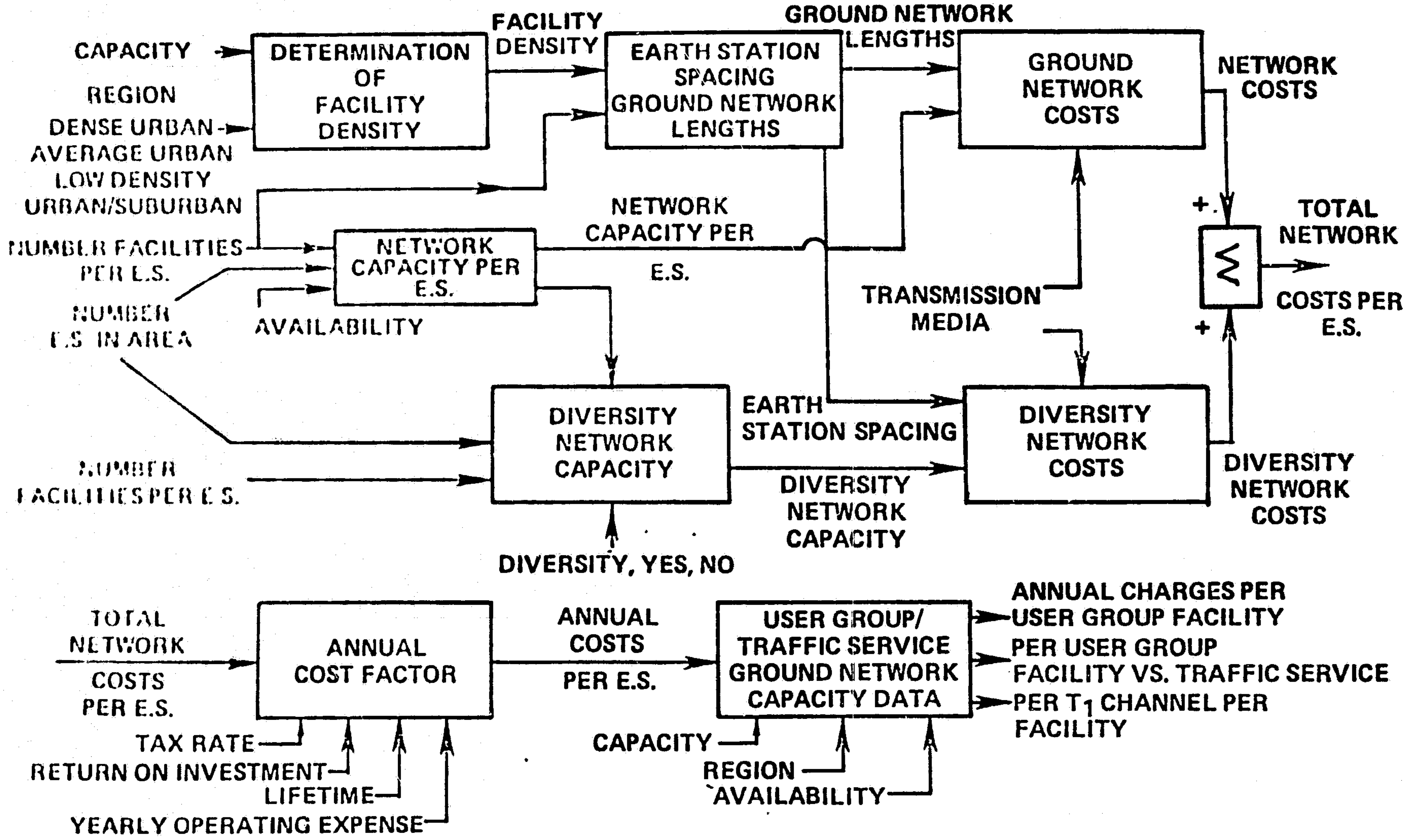

Figure 6.2-1. Ground Networking Cost Computation

facilities/sq. km. For a light urban area (like Houston), this density is 0.008 facilities per sq. km. and for a heavy urban area (like New York City), this density is 0.065 facilities per sq. km.. If the peak aggregate capacity is increased to 15 Gbps, the above facility densities are tripled.

A second important parameter affecting network length and cost is the number of facilities per earth station which in turn is related to the capacity per earth station. In the cost analysis, the number of facilities per earth station is varied from two, five and ten per earth station. The capacity of each earth station is varied from 6.2 Mbps ($4T_1$), 20 Mbps ($13T_1$) and 40 Mbps ($26T_1$).

In determination of network length, the coverage area of each earth station is equal to the number facilities per earth station divided by the facility density. The average length of network between earth station and facility is assumed to range over one-half coverage area and equals

$$\frac{1}{2\pi}\sqrt{\frac{\text{NUMBER FACILITIES PER ES}}{\text{FACILITY DENSITY}}}$$

The spacing between earth stations equals

$$\frac{2}{2\pi}\sqrt{\frac{\text{NUMBER FACILITIES PER ES}}{\text{FACILITY DENSITY}}}$$

The network costs are a function of the length given above and the T_1 capacity. The T_1 capacity per average facility varies from 2.71 for an availability of 99.5% to 3.22 for an availability of 99.9%. The network capacity is greater than the earth station capacity because of inefficiency in transmission. The computation of network costs as a function of transmission mode, capacity and length is presented in Section 3.6.

The diversity network is costed based on a requirement that its capacity be one-half earth station capacity ($4T_1$, $13T_1$ or $26T_1$) and spacing between earth stations as given above.

For the SS-FDMA system described in Section 6.1 (15 Gbps, availability 99.9%), the installed ground network costs per earth station given in Table 6.2-1 for microwave radio, fiber optic cable and coaxial cable links and $4T_1$, $13T_1$ and $26T_1$ earth stations.

The cost per user facility is based on the peak capacity per user facility given in Tables 2.3-9 and 2.3-10 for respective availabilities of 99.5% and 99.9%. The annual network costs utilize the factor Fo (=0.489) described in Section 3.6. For the system whose installed costs are given in Table 6.2-1, the annual ground network service charges are given in Tables 6.2-2 for an earth station with a capacity of 20 Mbps ($13T_1$).

6.3 EARTH STATION SERVICE CHARGES

The determination of earth station service costs are based on the costing algorithms presented in Section 3.5. Figure 6.3-1 presents the procedure for determination of earth station service charges for shared service with networking while Figure 6.3-2 presents a similar procedure for a standalone earth station. The major difference is that in shared service a single size earth station will exist with the design varying in the different rain zones to a small degree. However, for standalone service, each facility will have a different size earth station depending on its capacity. In shared service, the user is charged according to his share of the earth stations peak capacity. For a system with diversity, the earth station components are assumed to be non-redundant for costing purposes.

Table 6.2-1. Installed Ground Network Charges ($1000)

FDMA SYSTEM
AVAILABILITY= 99.9%

NO. OF T1 LINES	MICROWAVE	OPTIC CABLE	COAXIAL CABLE
4	196.16	323.96	153.69
13	491.35	891.26	601.97
26	1043.8	1913.5	1509.6

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Table 6.2-2. Annual Ground Network Charges vs. Class/Traffic Service ($1K)

FDMA SYSTEM
AVAILABILITY= 99.9%

USER CLASS	VOICE	VIDEO CONF.	VIDEO INFO. SERV.	DATA MESS.	DATA COMPUT.	TOTAL USER
LARGE BUSINESS	31.86	42.75	0.00	2.30	3.34	80.25
SMALL BUSINESS	5.68	0.00	0.00	.85	.89	7.43
GOV. AGENCIES	43.18	41.68	83.37	3.77	6.46	178.47
MUNICIPALITIES	5.85	0.00	0.00	.85	.73	7.43
INSTITUTIONS	12.60	38.02	76.10	2.07	2.96	131.75
HOMES AND CONDOS	38.41	0.00	74.13	0.00	1.15	113.79

For the SS-FDMA system, the installed earth station costs versus capacity in rain zone D is given in Table 6.3-1. In a manner similar to the ground network charges, the annual earth station costs are obtained from the factor FO and the distribution of these charges to the user is based on the peak capacity of the facility. For the 13T_1 earth station given in Table 6.3-1, the annual earth station service charges per user facility and traffic service is given in Table 6.3-2.

6.4 TOTAL ANNUAL SERVICE CHARGES

The total annual user charges per user facility are the sum of the space segment charges (typically Table 6.1-2), ground network charges (typically Table 6.2-2) and earth station charges (Table 6.3-2). Table 6.4-1 summarizes the total annual service charges for the example presented.

Another service cost given in Table 6.4-1 is the total cost per T_1 channel with the breakdown of the contributions of the space segment, ground network and earth station. The cost per T_1 channel is a useful criteria in comparing the relative costs of different systems.

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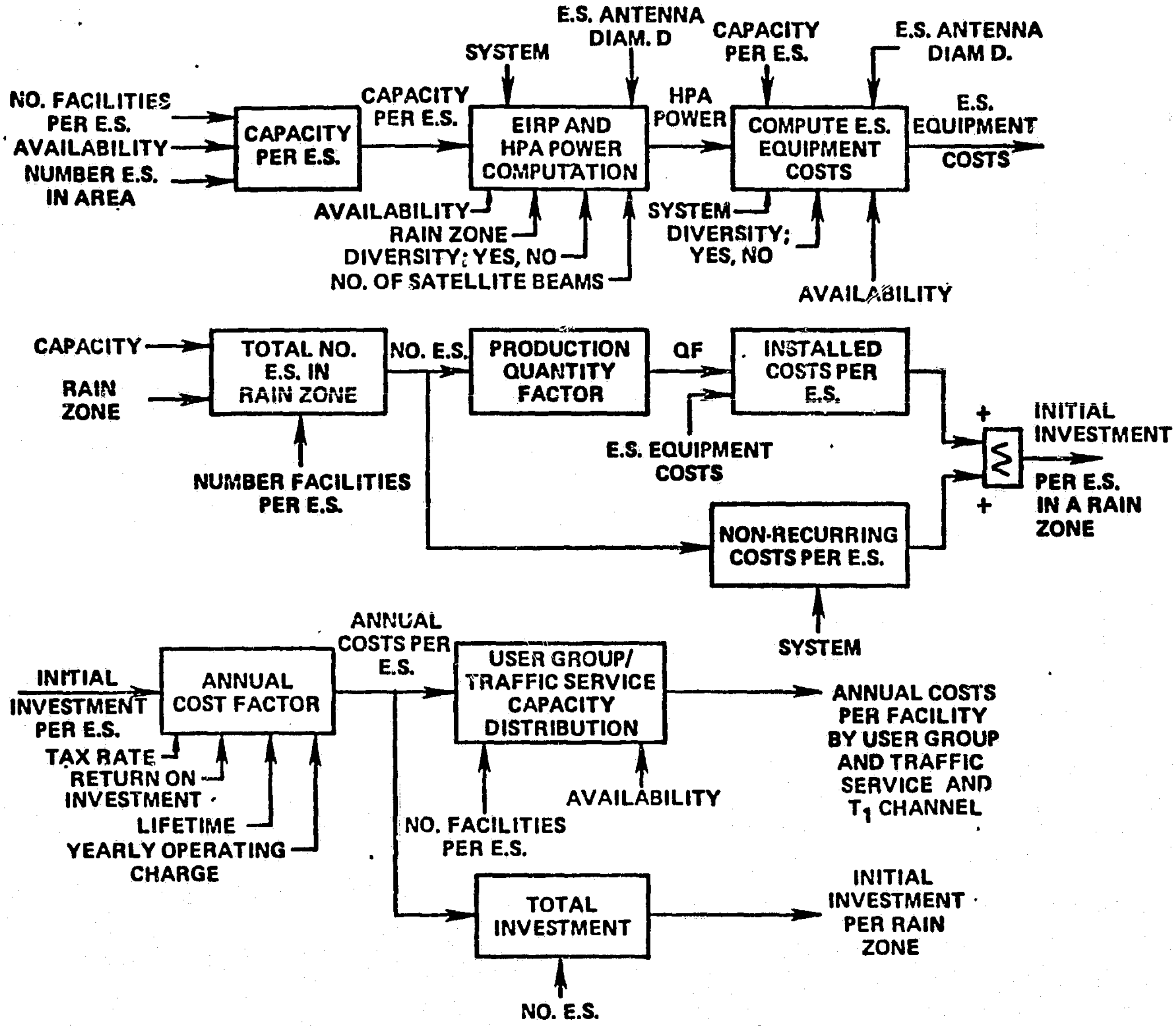

Figure 6.3-1. Earth Station Cost Computation
(Shared Service, Networking)

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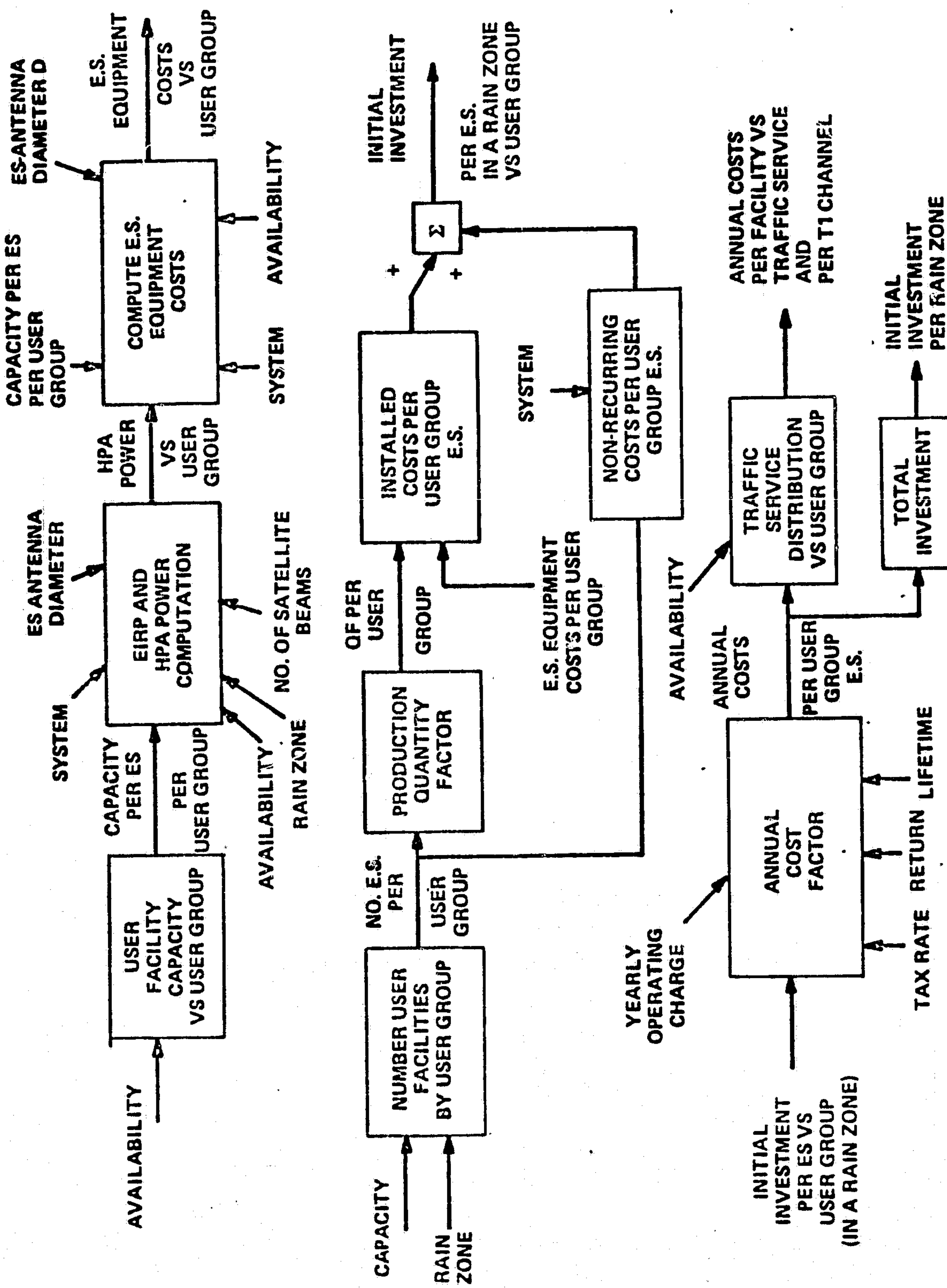

Figure 6.3-2. Earth Station Cost Computation (Standalone Facility)

Table 6.3-1. Installed Earth Station Costs ($1000)

FDMA SYSTEM
AVAILABILITY= 99.9% ; Rain Zone D

NO. OF T1 LINES	COST
4	234.8
13	297.8
26	388.8

Table 6.3-2. Annual Earth Station Charges vs. Class/Traffic Service ($1000)

FDMA SYSTEM
AVAILABILITY= 99.9% ; Rain Zone D

USER CLASS	VOICE	VIDEO CONF.	VIDEO INFO. SERV.	DATA MESS.	DATA COMPUT.	TOTAL USER
LARGE BUSINESS	23.35	31.34	0.00	1.68	2.45	58.82
SMALL BUSINESS	4.16	0.00	0.00	.63	.65	5.44
GOV. AGENCIES	31.65	30.55	61.11	2.76	4.74	130.81
MUNICIPALITIES	4.29	0.00	0.00	.62	.53	5.44
INSTITUTIONS	9.23	27.87	55.78	1.52	2.17	96.57
HOMES AND CONDOS	28.15	0.00	54.34	0.00	.84	83.40

From the data in Table 6.4-1 and the facility traffic service characteristics in Table 2.3-10, the costs per given service are presented in Table 6.4-2.

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Table 6.4-1. Total Annual Charges vs. Class/Traffic Service (1000)

FDMA SYSTEM
AVAILABILITY= 99.9%

USER CLASS	VOICE	VIDEO CONF.	VIDEO INFO. SERV.	DATA MESS.	DATA COMPUT.	TOTAL USER
LARGE BUSINESS	188.04	202.26	0.00	10.96	15.75	417.04
SMALL BUSINESS	31.10	0.00	0.00	3.80	3.54	38.44
GOV. AGENCIES	276.76	200.40	400.88	18.15	31.13	927.34
MUNICIPALITIES	31.40	0.00	0.00	3.80	3.26	38.44
INSTITUTIONS	74.97	194.07	388.23	10.56	15.09	682.94
HOMES AND CONDOS	199.39	0.00	384.83	0.00	5.98	590.70

THE TOTAL COST PER T1 LINE IS =96139.8
SPACE SEGMENT CONTRIBUTION=64091.2
GROUND SEGMENT CONTRIBUTION=18493.4
EARTH STA SEGMENT CONTRIBUTION=13555.2

Table 6.4-2. Unit Service Charges

User Class	Voice $/Call-Hr	Video Conf. $/Conf.-Hr.	Video Info $/Hr.	Data Message $/56 KBPS-Hr.	Data Computer $9.6KBPS
Large Business	1.81	97.24	0	1.76	.30
Small Business	1.87	0	0	1.83	.34
Gov't Agencies	1.75	96.35	192.73	1.75	.30
Municipalities	1.87	0	0	1.83	.34
Institutions	1.80	103.30	186.65	1.69	.29
Homes & Condos	1.92	0	185.01	0	.29

SECTION 7

TASK 6 - SENSITIVITY ANALYSIS

SECTION 7

TASK 6 - SENSITIVITY ANALYSIS

7.1 SENSITIVITY ANALYSIS OF BASIC SYSTEMS

The Sensitivity Analysis examines the effect of variation of system parameters on annual cost. The overall procedure is outlined in Figure 7.1-1. The cost analysis approach of Section 6 is used in determination of total system costs. The range of parameters used in the sensitivity analysis is presented in Table 7.1-1.

Table 7.1-1. Sensitivity Analysis Parameters

- Systems:
  - SS-FDMA
  - SS-TDMA/fixed beam
  - SS-TDMA/scanning beam
  - HYBRID
- Peak Aggregate Traffic
  - 3 Gbps; 5 Gbps; 15, Gbps
- Availability 99.5% (3 Gbps, 5 Gbps)
  - 99.9% (15 Gbps)
- Earth Station Capacity:
  - 1 T1 (standalone); 4T1 (6 Mbps); 13T1 (20 Mbps) and 26T1 (40 Mbps)
- Burst Rates (SS-TDMA):
  - 80 Mbps (4T1 ES); 128 Mbps (13T1 ES) and 256 Mbps (26T1 ES)
- Urban Area Facility Density:
  - Low, Average, High
- Networking Media:
  - Microwave Radio, Fiber Optics, Coaxial Cable
- Earth Station Antenna Diameter:
  - 3 meters, 5 meters, 7 meters
- Number of Satellite Beams:
  - 19, 32, 46, 68, 100
- CONUS Coverage:
  - Rain Zones D, E, B (C,F)
- Diversity:
  - All Rain Zones; In Zone E Only; and No Diversity

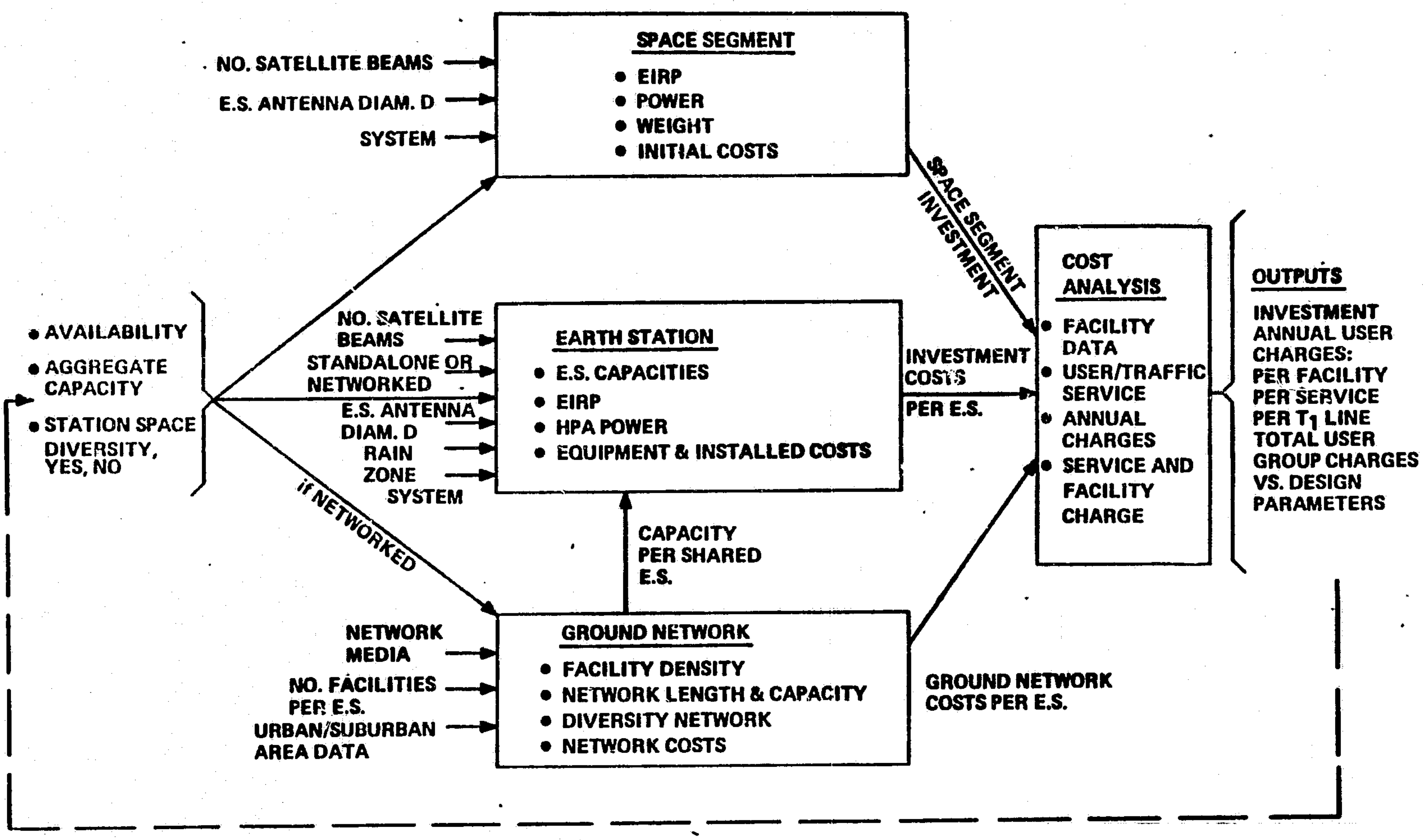

Figure 7.1-1. Sensitivity Analysis Procedure

Other system parameters which have been assumed in the sensitivity analysis are listed in Table 7.1-2.

Table 7.1-2. System Parameters Assumed in Sensitivity Analysis

• Satellite Lifetime	10 years
• Ground Network Lifetime	15 years
• Earth Station Lifetime	10 years
• Space Segment Yearly Expense	$10 million
• Earth Station/Ground Network Yearly Expense	15% of Installed Cost
• Space Segment Usage Growth Rate	0.246
• Return on Investment	20%
• Tax Rate	46%

7.1.1 NORMALIZED ANNUAL SERVICE COSTS

The annual service cost per T1 channel versus number of satellite beams, earth station antenna diameter, and earth station capacity (light, average and heavy urban facility densities) are given in the following figures:

System	Parameter	Figure
1. SS-FDMA, 15 Gbps Avail. 99.9%; Diversity; Microwave Radio Network	No. Satellite Beams Antenna Diameters Earth Station Capacity	7.1-2 7.1-3 7.1-4
2. SS-TDMA/Fixed Beam System 1 15 Gbps; Avail. 99.9%; Diversity; Microwave Radio Network	No. Satellite Beams Antenna Diameter Earth Station Capacity	7.1-5 7.1-6 7.1-7
3. SS-TDMA/Fixed Beam System 2 15 Gbps; Avail. 99.9%; Diversity in E-zone only; Microwave Radio Network	No. Satellite Beams Antenna Diameter Earth Station Capacity	7.1-8 7.1-9 7.1-10
4. SS-TDMA/Fixed Beam System 3 3 Gbps; Avail. 99.5%; No-Diversity; Microwave Radio Network	No. Satellite Beams Antenna Diemeter Earth Station Capacity	7.1-11 7.1-12 7.1-13
5. SS-TDMA/Fixed Beam System 4 3 Gbps; Avail. 99.5%; Standalone; Earth Station Capacity 4T1	No. Satellite Beams Antenna Diameter	7.1-14 7.1-15

6. SS-TDMA/Fixed Beam System 5 5 Gbps; Avail. 99.5%; No-Diversity; Microwave Radio Network	No. Satellite Beams Antenna Diameter Earth Station Capacity	7.1-16 7.1-17 7.1-18
7. SS-TDMA/Fixed Beam System 6 5 Gbps, Avail. 99.5%; Standalone; Earth Station Capacity 4T1	No. Satellite Beams Antenna Diameter	7.1-19 7.1-20
8. HYBRID System 1 15 Gbps; Avail. 99.9%; Diversity; Microwave Radio Network	No. Satellite Beams Antenna Diameter Earth Station Capacity	7.1-21 7.1-22 7.1-23
9. HYBRID System 2 3 Gbps; Avail. 99.5%; No Diversity; Microwave Radio Network	No. Satellite Beams Antenna Diameter Earth Station Capacity	7.1-24 7.1-25 7.1-26
10. HYBRID System 3 5 Gbps; Avail. 99.5%; No Diversity; Microwave Radio Network	No. Satellite Beams Antenna Diameter Earth Station Capacity	7.1-27 7.1-28 7.1-29
11. SS-TDMA/Scanning Beam System 1 15 Gbps; Avail. 99.9%; Microwave Radio Network	No. Satellite Beams Antenna Diameter Earth Station Capacity	7.1-30 7.1-31 7.1-32
12. SS-TDMA/Scanning Beam System 2 3 Gbps; Avail. 99.5%; No. Diversity; Microwave Radio Network	No. Satellite Beams Antenna Diameter Earth Station Capacity	7.1-33 7.1-34 7.1-35
13. SS-TDMA/Scanning Beam System 3 5 Gbps; Avail. 99.5%; No Diversity; Microwave Radio Network	No. Satellite Beams Antenna Diameter Earth Station Capacity	7.1-36 7.1-37 7.1-38

Some of the conclusions are:

1. Largest possible antenna diameter (7 meters) results in minimum costs for all systems with ground networking because of significant space segment power reduction. By reducing the earth station antenna diameter to 5 meters, the costs increase by about 10 percent.

2. A 20 Mbps (13T1) earth station capacity approaches the conditions for minimum cost with further increases in capacity resulting in little advantage (less than five percent cost reductions). However, reducing the earth station capacity to 4T1 results in significant cost increases (greater then 25 percent).

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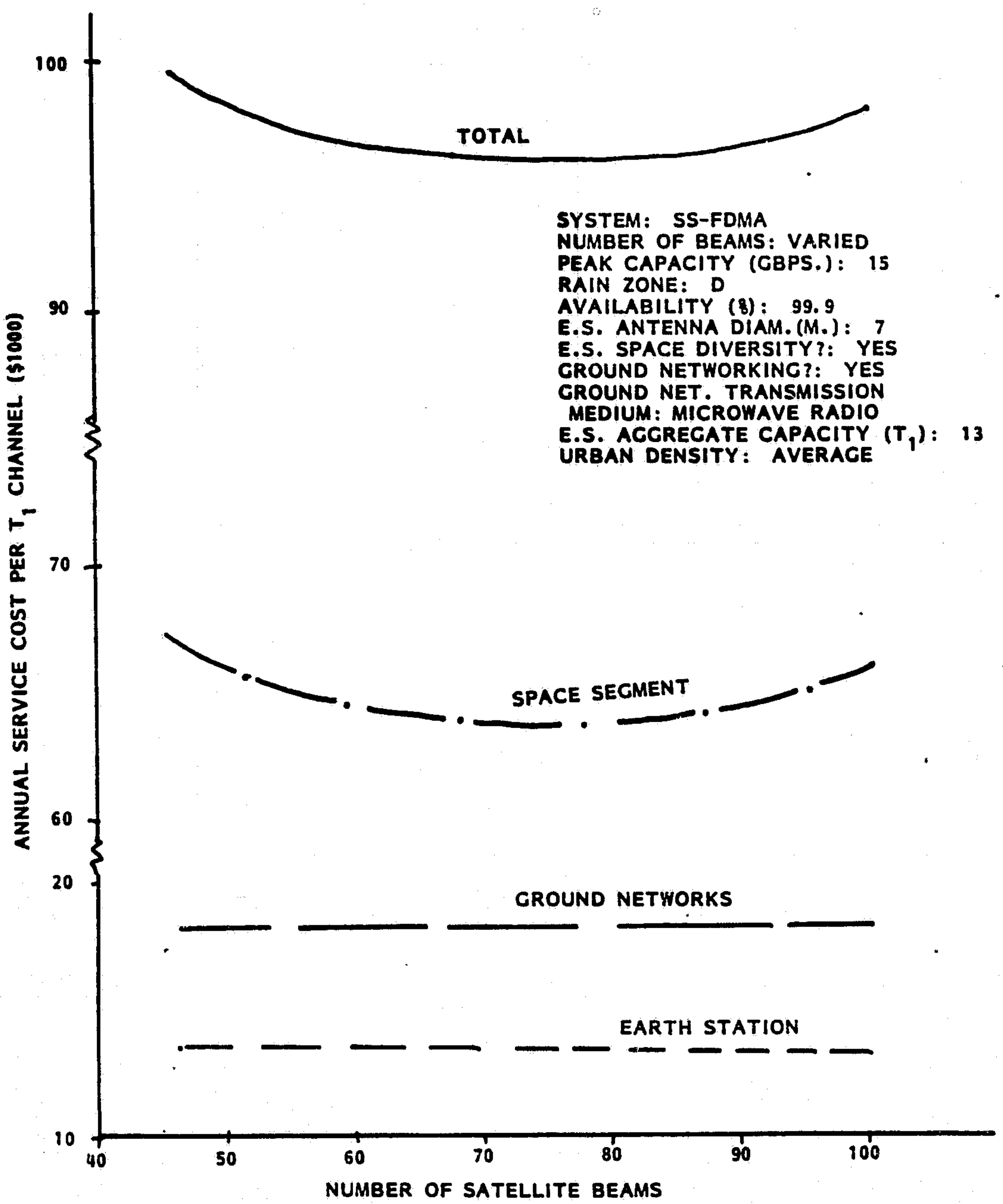

Figure 7.1-2. SS-FDMH Number of Satellite Beams vs Service Costs

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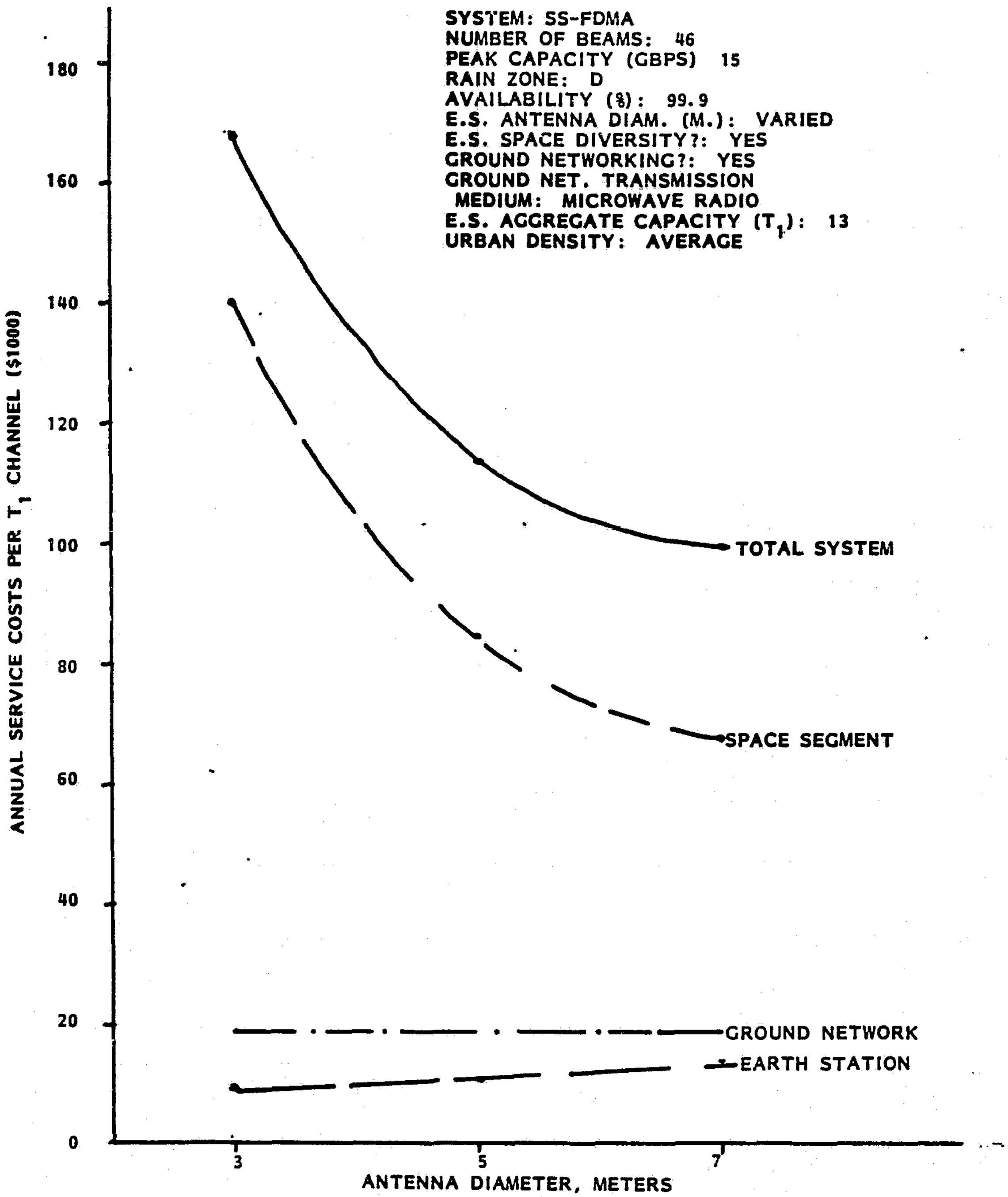

Figure 7.1-3. SS-FDMH Earth Station Antenna Diameter vs Service Costs

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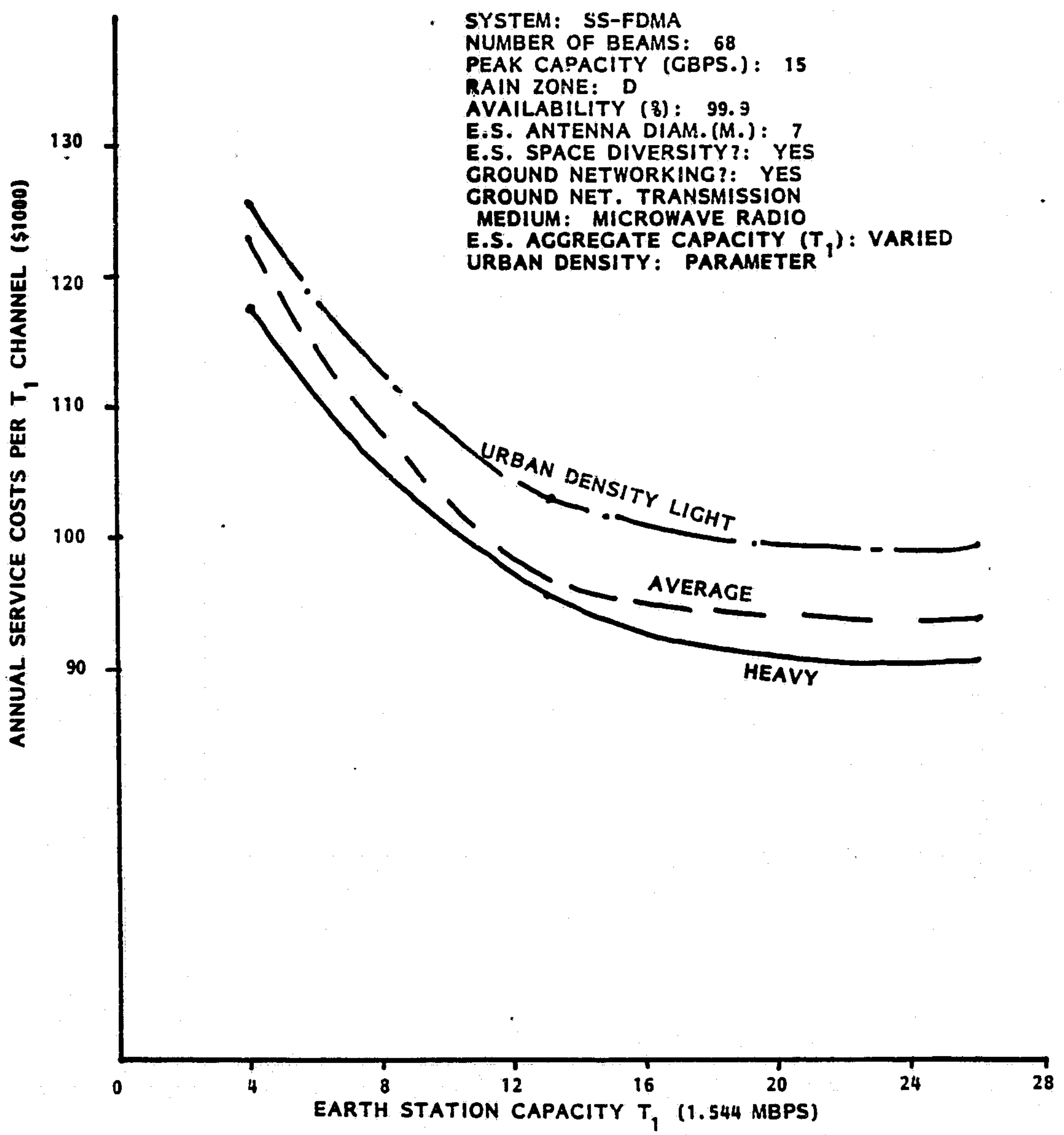

Figure 7.1-4. SS-FDMA Earth Station Capacity and Urban Density vs Service Costs

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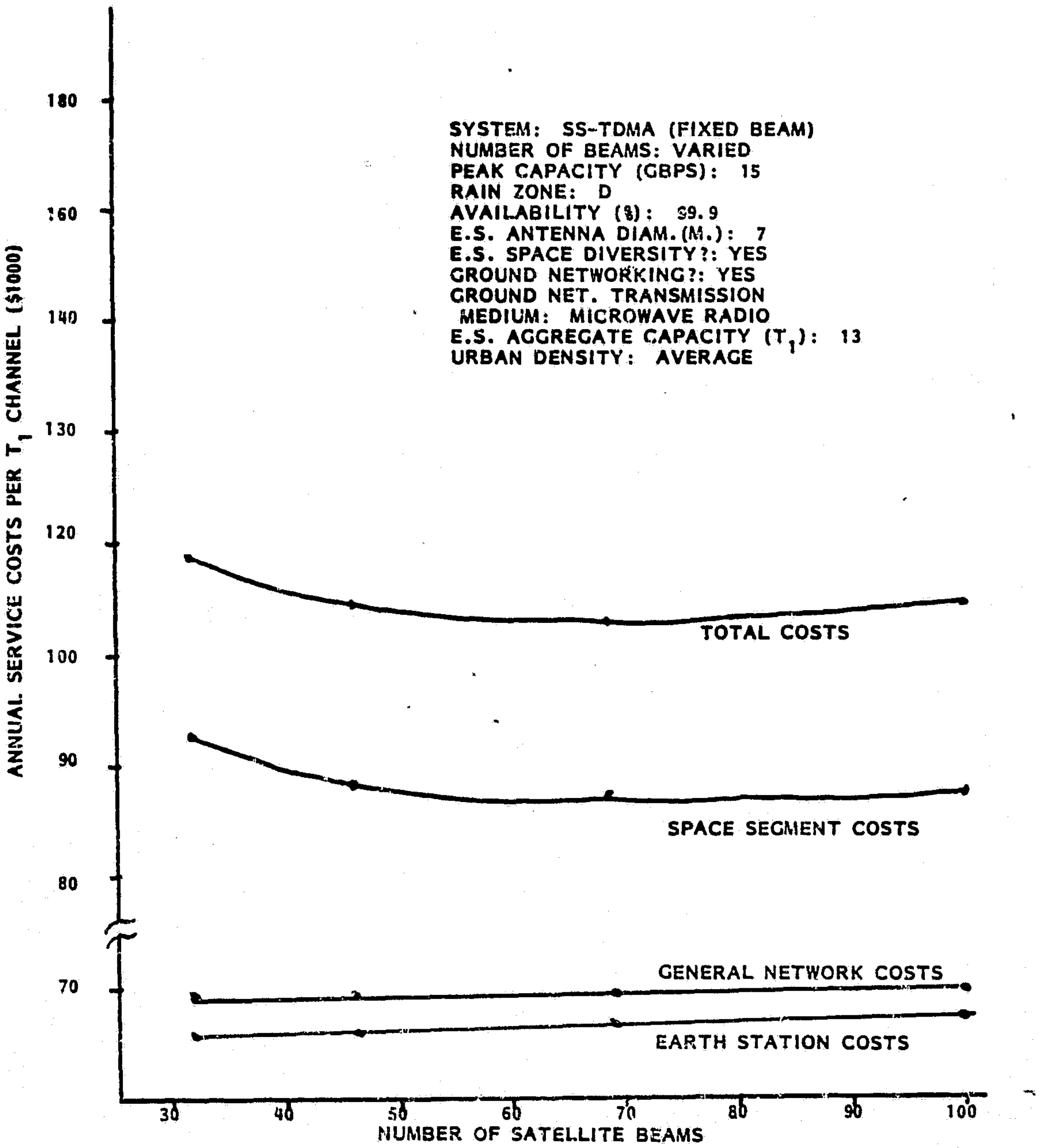

Figure 7.1-5. SS-TDMA/FB System 1 - Number of Satellite Beams vs Service Costs

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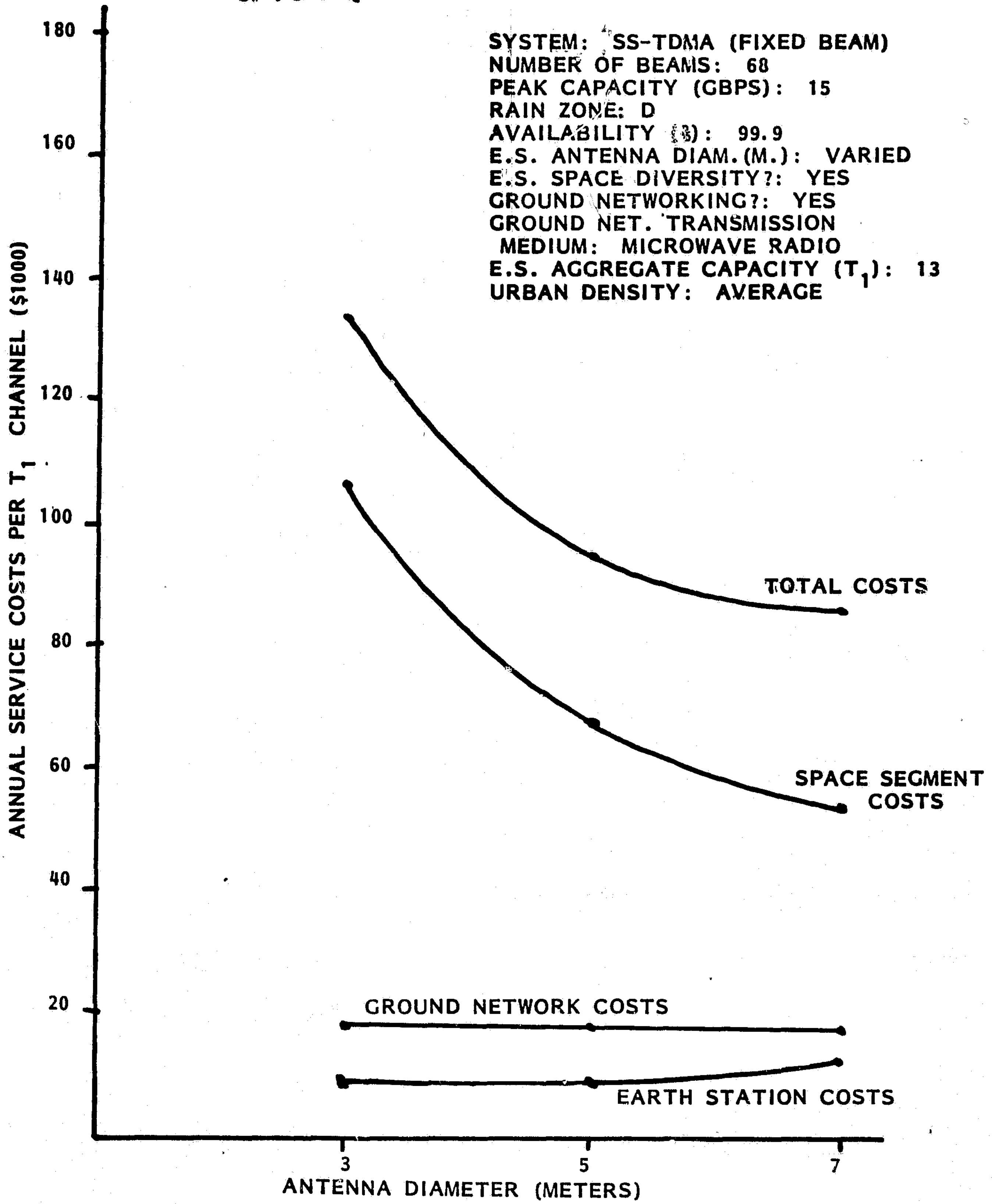

Figure 7.1-6. SS-TDMM/FB System 1 - Earth Station Antenna Diameter vs Service Costs

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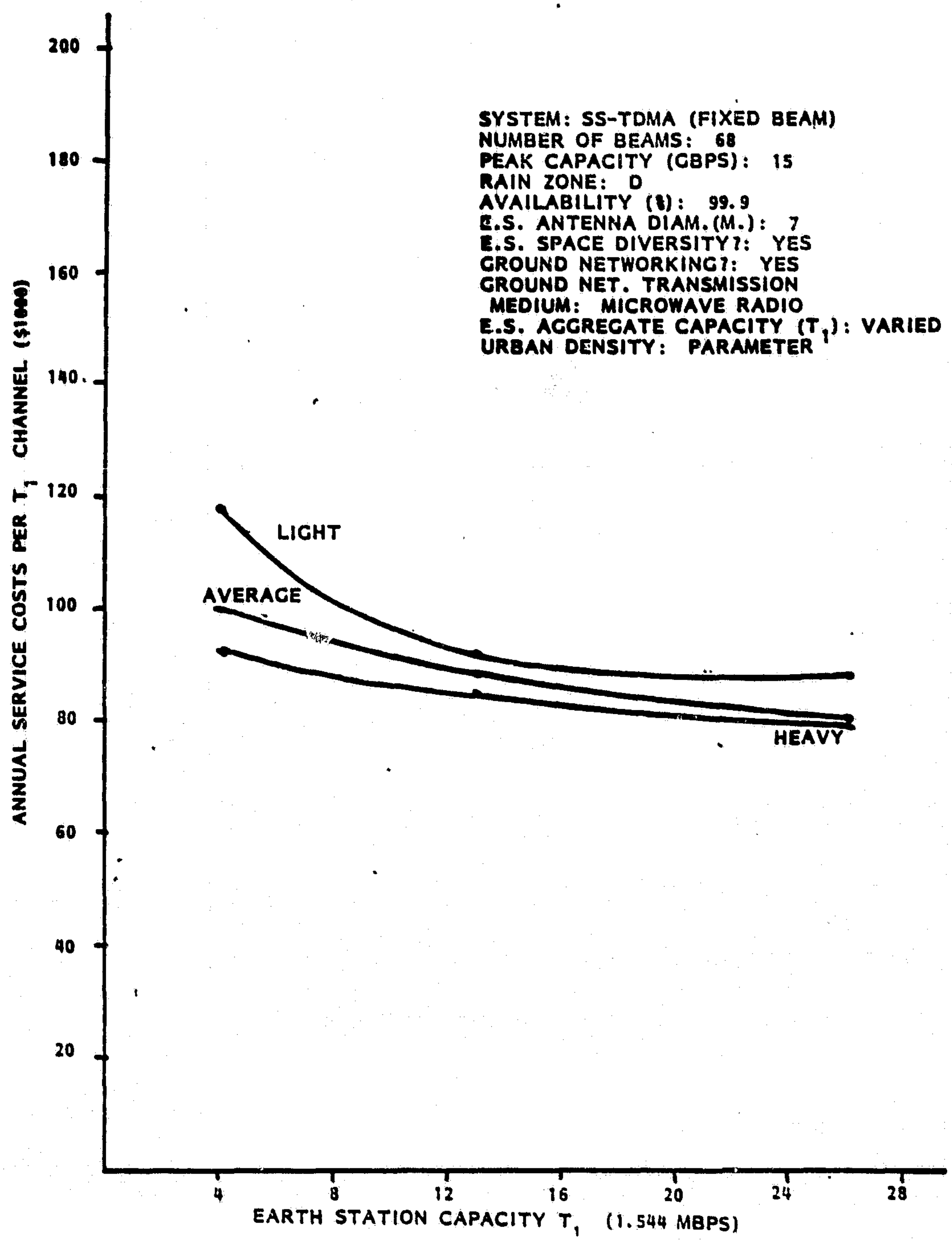

Figure 7.1-7. SS-TDMA/FB System 1 - Earth Station Capacity and Urban Density vs Service Costs

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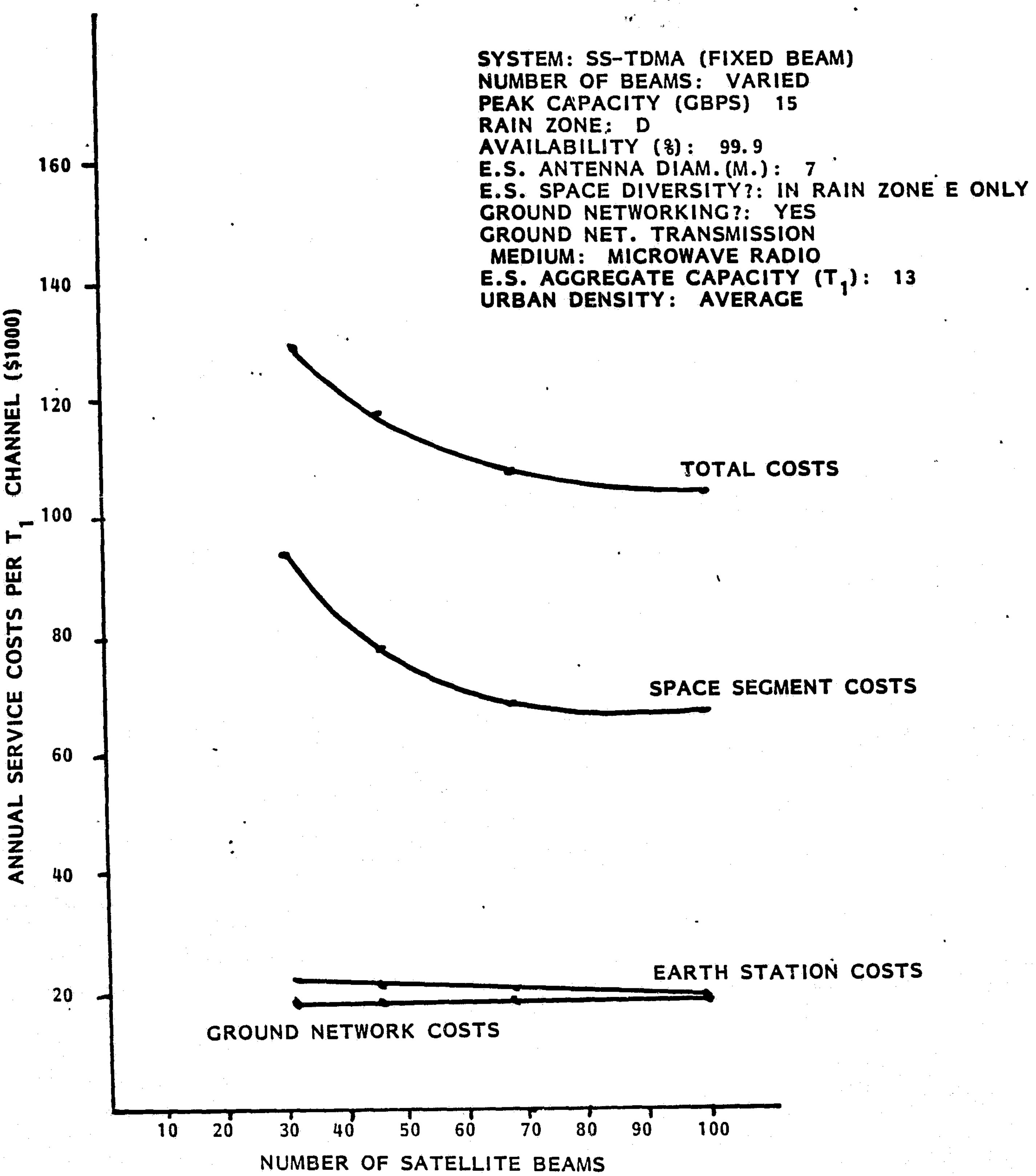

Figure 7.1-8. SS-TDMA/FB System 2 - Number of Satellite Beams vs Service Costs

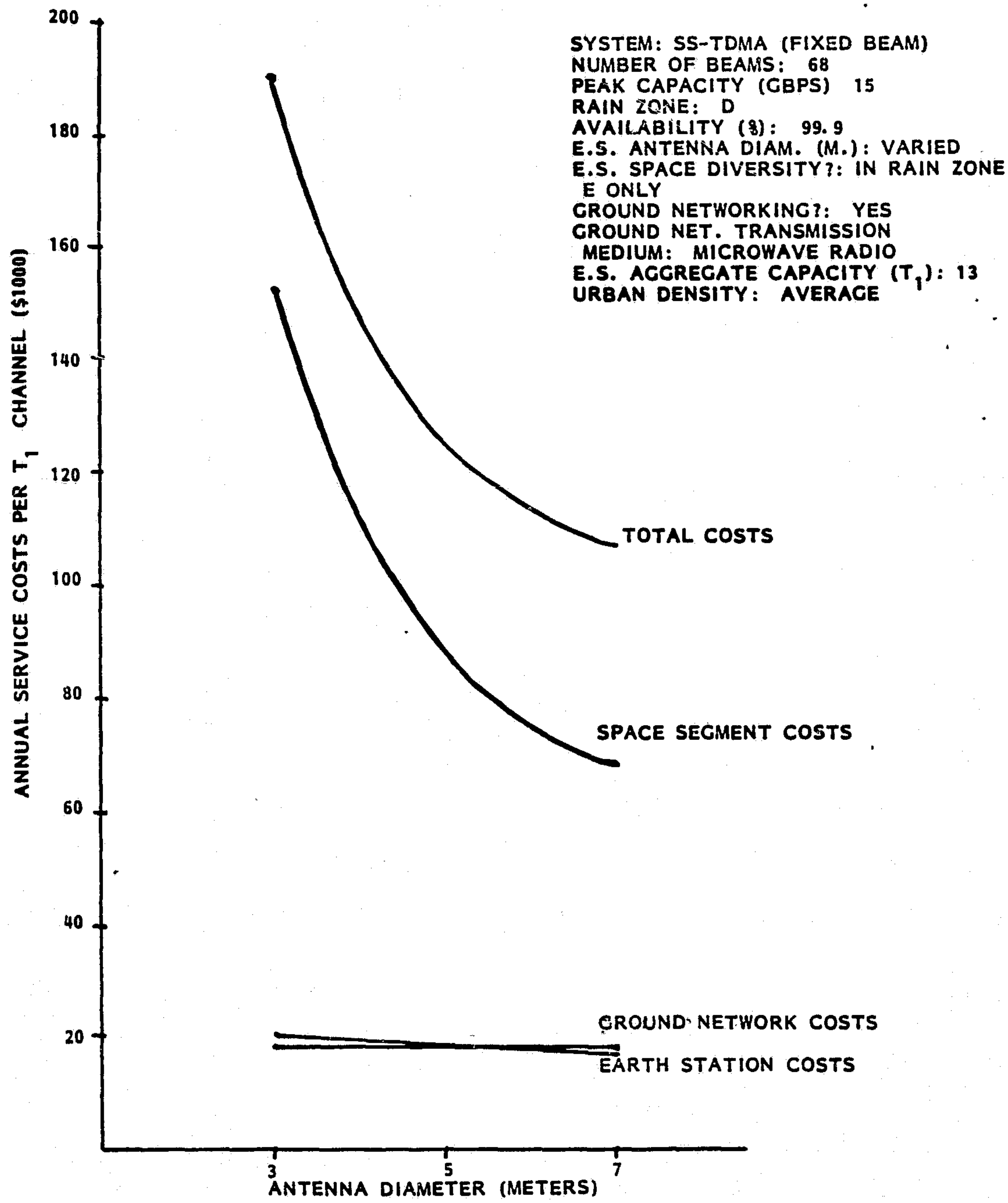

Figure 7.1-9. SS-TDMA/FB System 2 - Earth Station Antenna Diameter vs Service Costs

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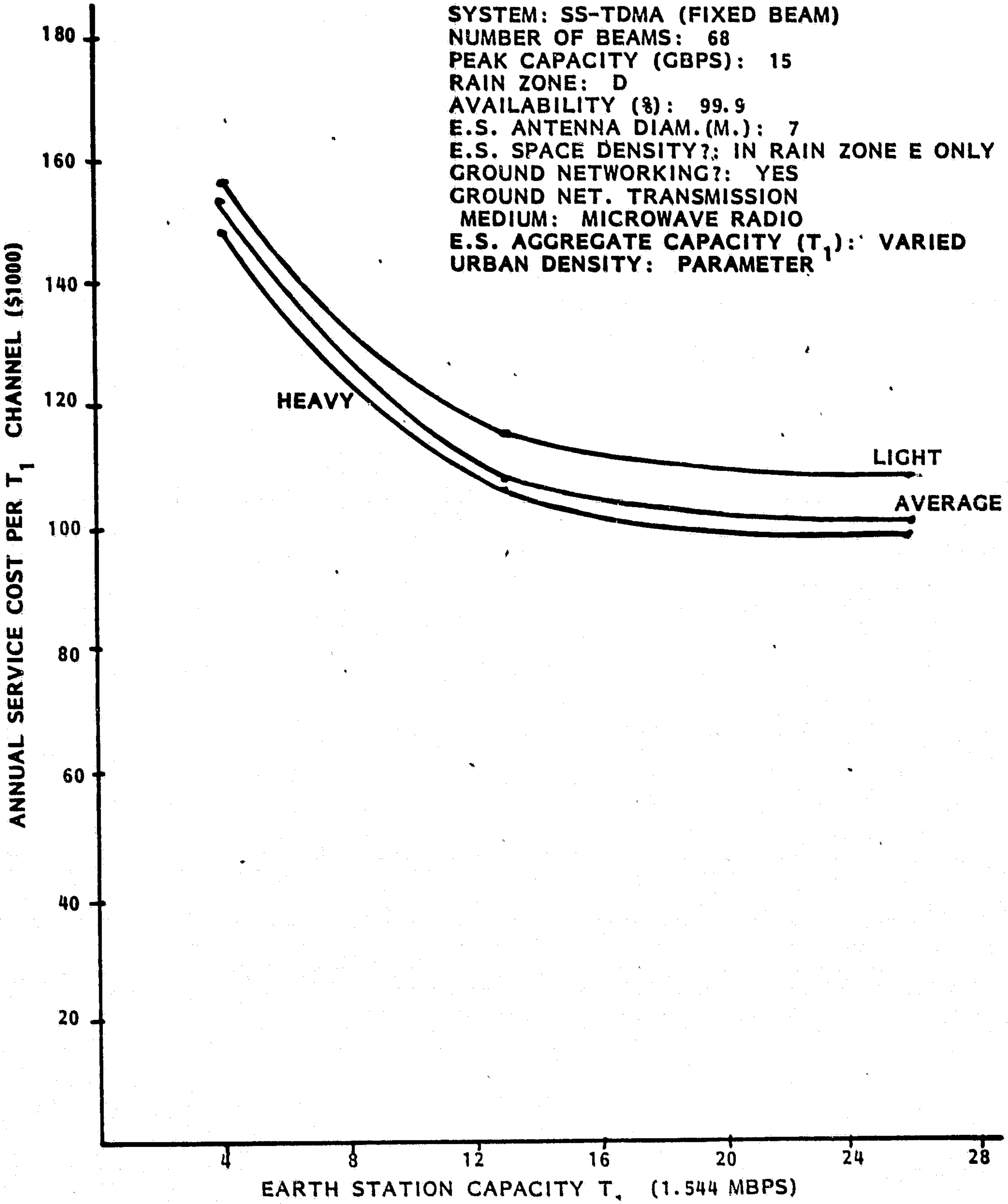

Figure 7.1-10. SS-TDMA/FB System 2 - Earth Station Capacity and Urban Density vs Service Costs

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SYSTEM: SS-TDMA (FIXED BEAM)
NUMBER OF BEAMS: VARIED
PEAK CAPACITY (GBPS): 3
RAIN ZONE: D
AVAILABILITY (%): 99.5
E.S. ANTENNA DIAM.(M): 5
E.S. SPACE DIVERSITY?: NO
GROUND NETWORKING?: YES
GROUND NET. TRANSMISSION MEDIUM: MICROWAVE RADIO
E.S. AGGREGATE CAPACITY (T_1): 13
URBAN DENSITY: AVERAGE

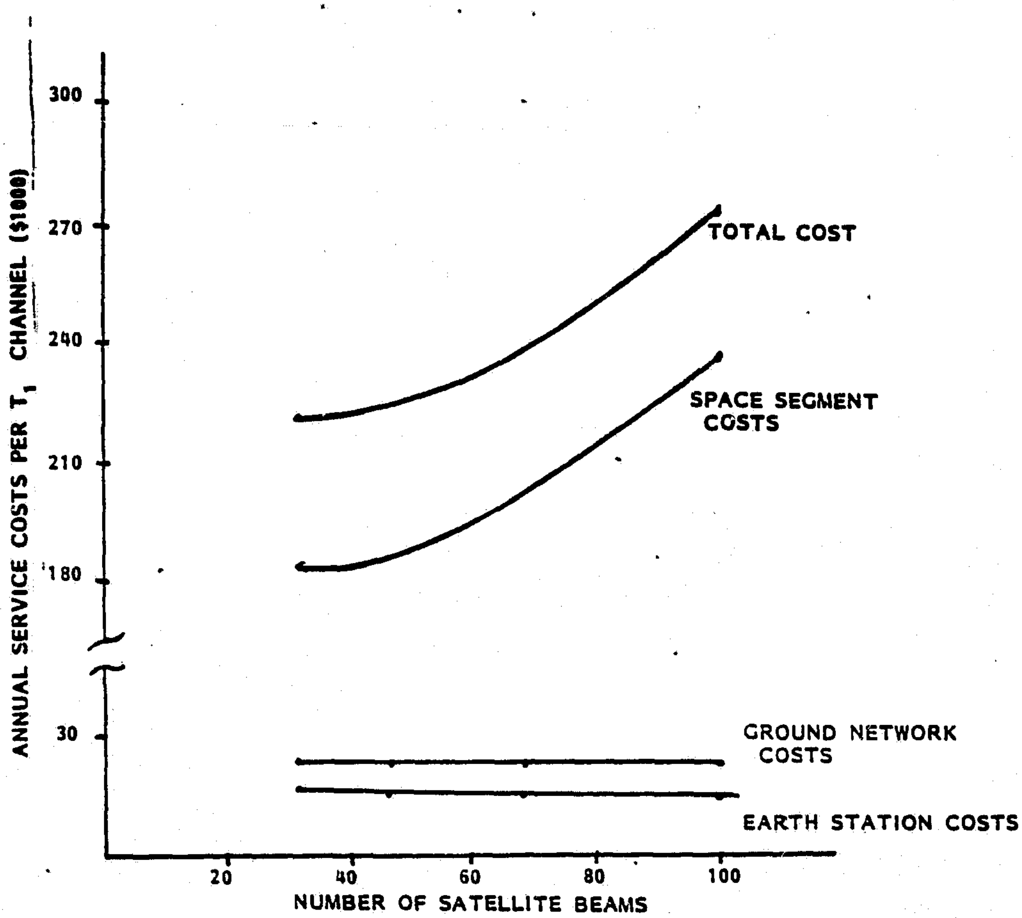

Figure 7.1-11. SS-TDMA/FB System 3 - Number of Satellite Beams vs Service Costs

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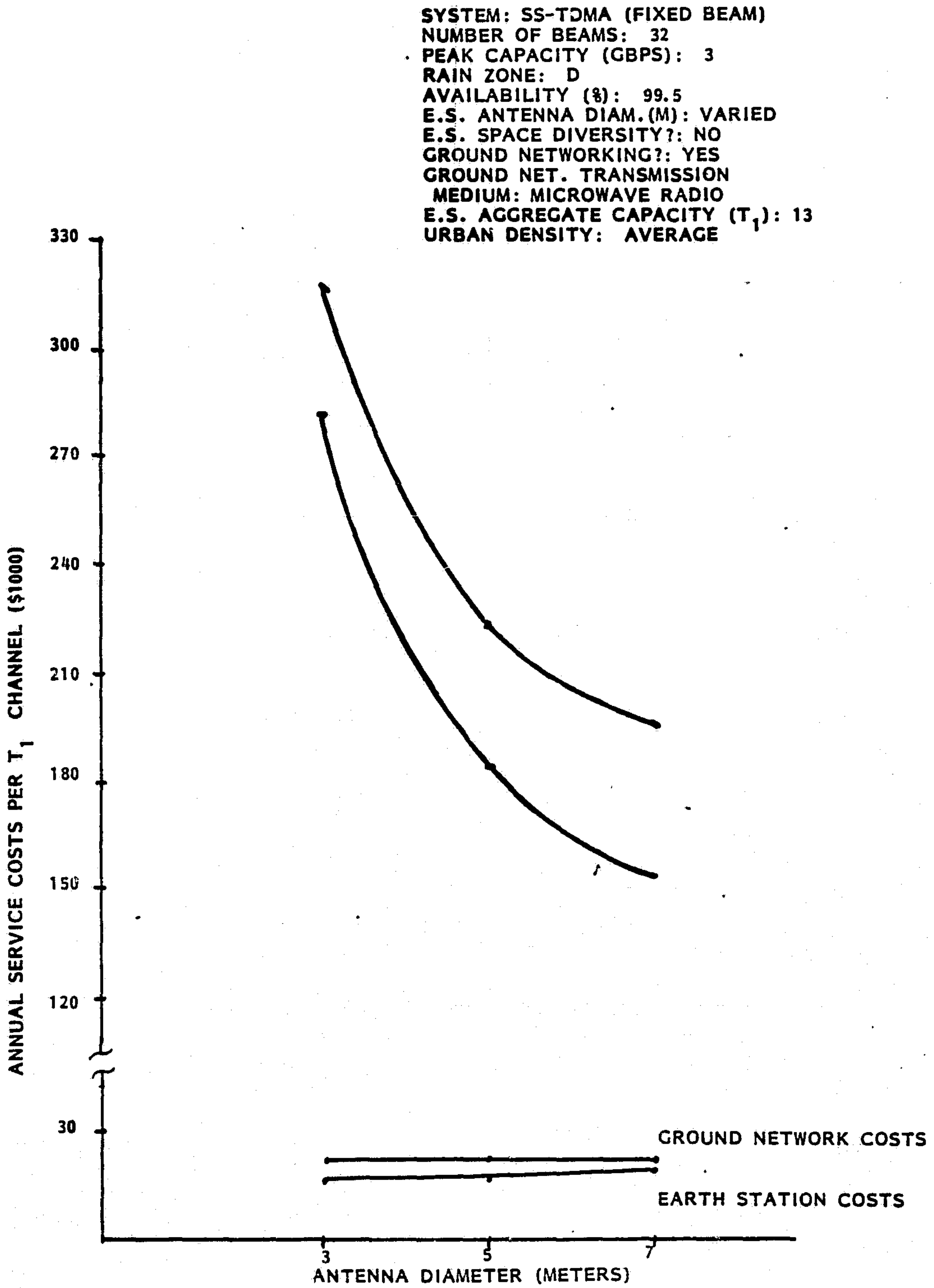

Figure 7.1-12. SS-TDMA/FB System 3 - Earth Station Antenna Diameter vs Service Costs

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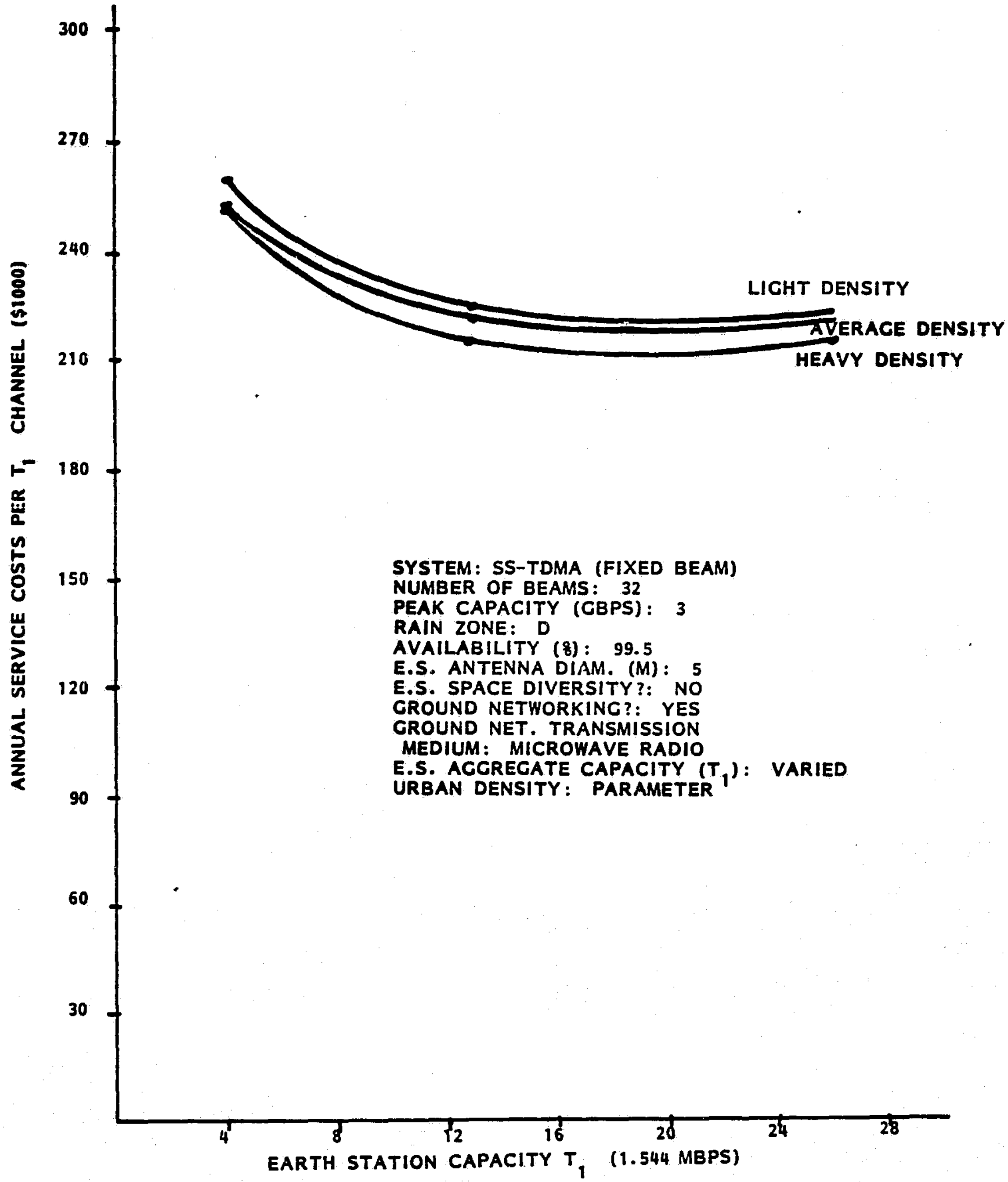

Figure 7.1-13. SS-TDMA/FB System 3 - Earth Station Capacity and Urban Density vs Service Costs

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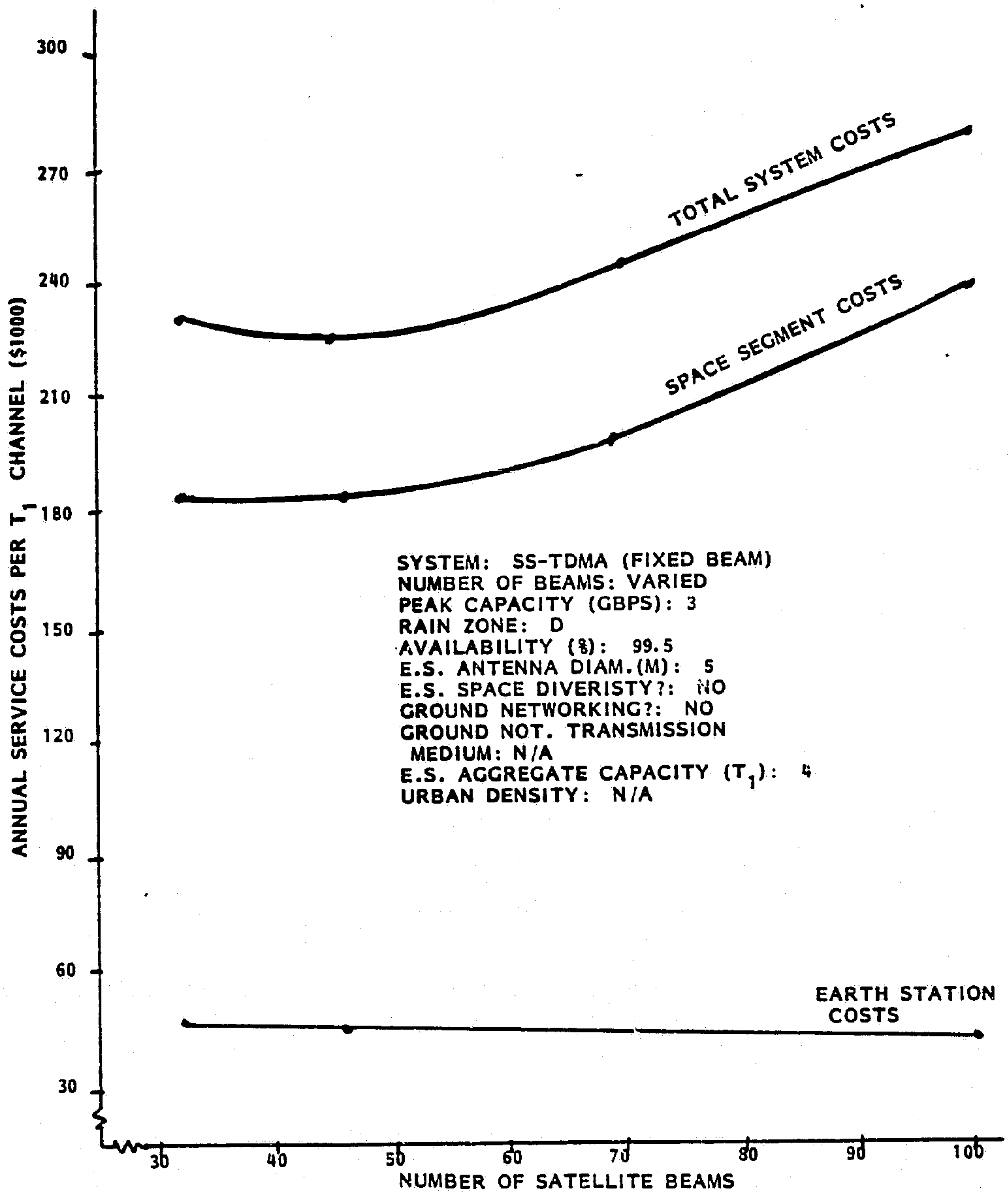

Figure 7.1-14. SS-TDMA/FB System 4 - Number of Satellite Beams vs Service Costs

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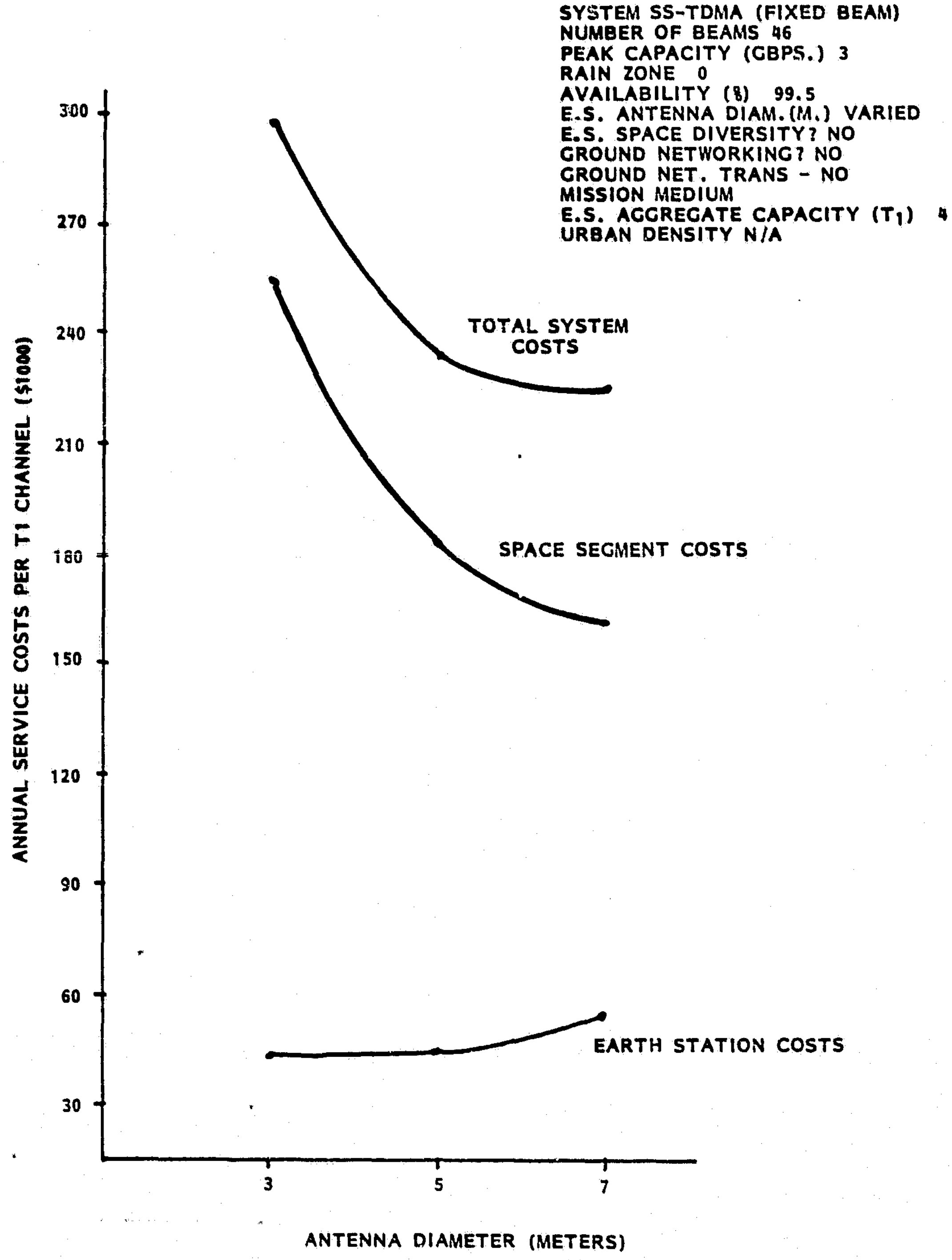

Figure 7.1-15. SS-TDMA/FB System 4 - Earth Station Antenna Diameter vs Service Costs

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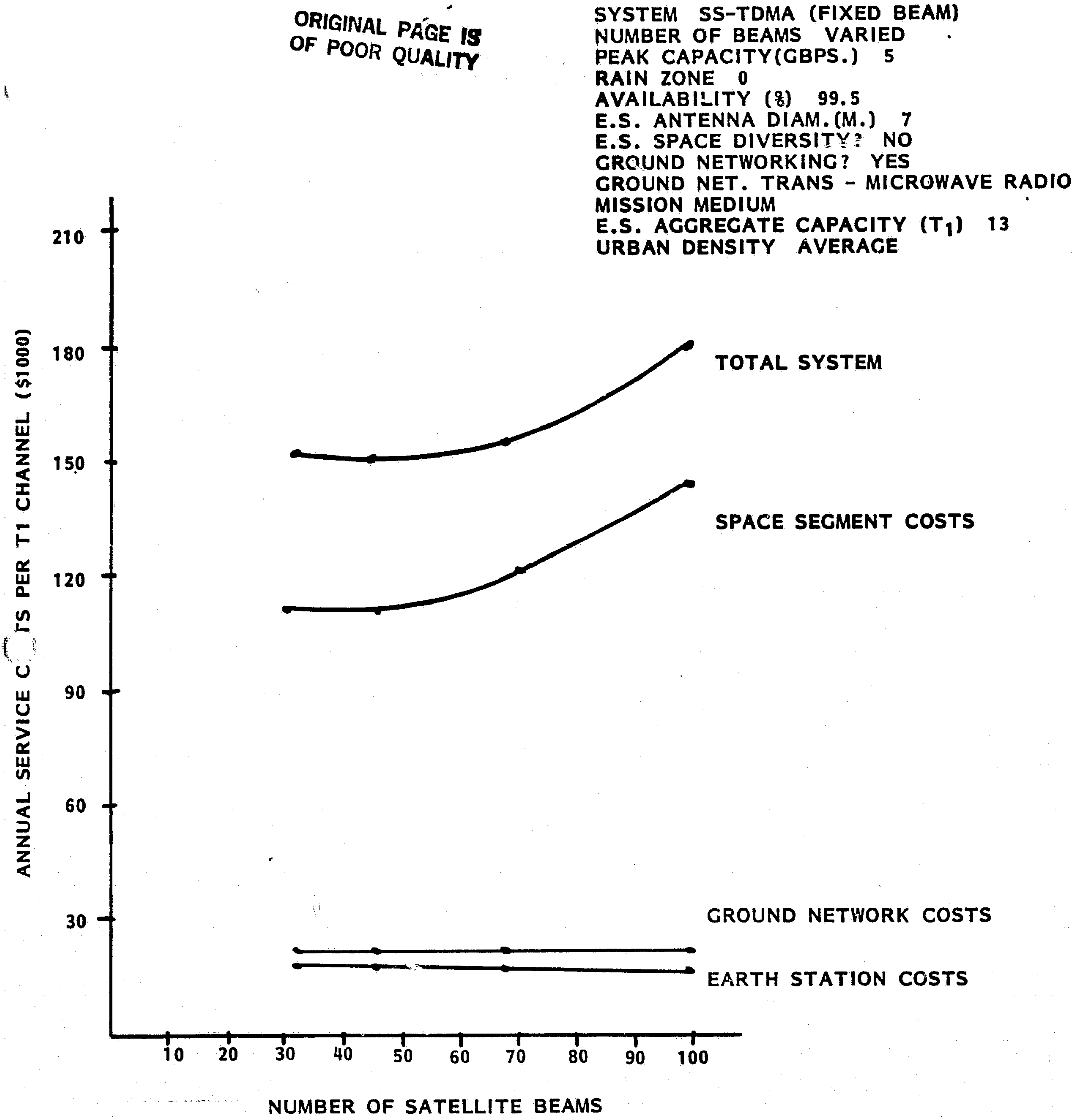

Figure 7.1-16. SS-TDMA/FB System 5 - Number of Satellite Beams vs Service Costs

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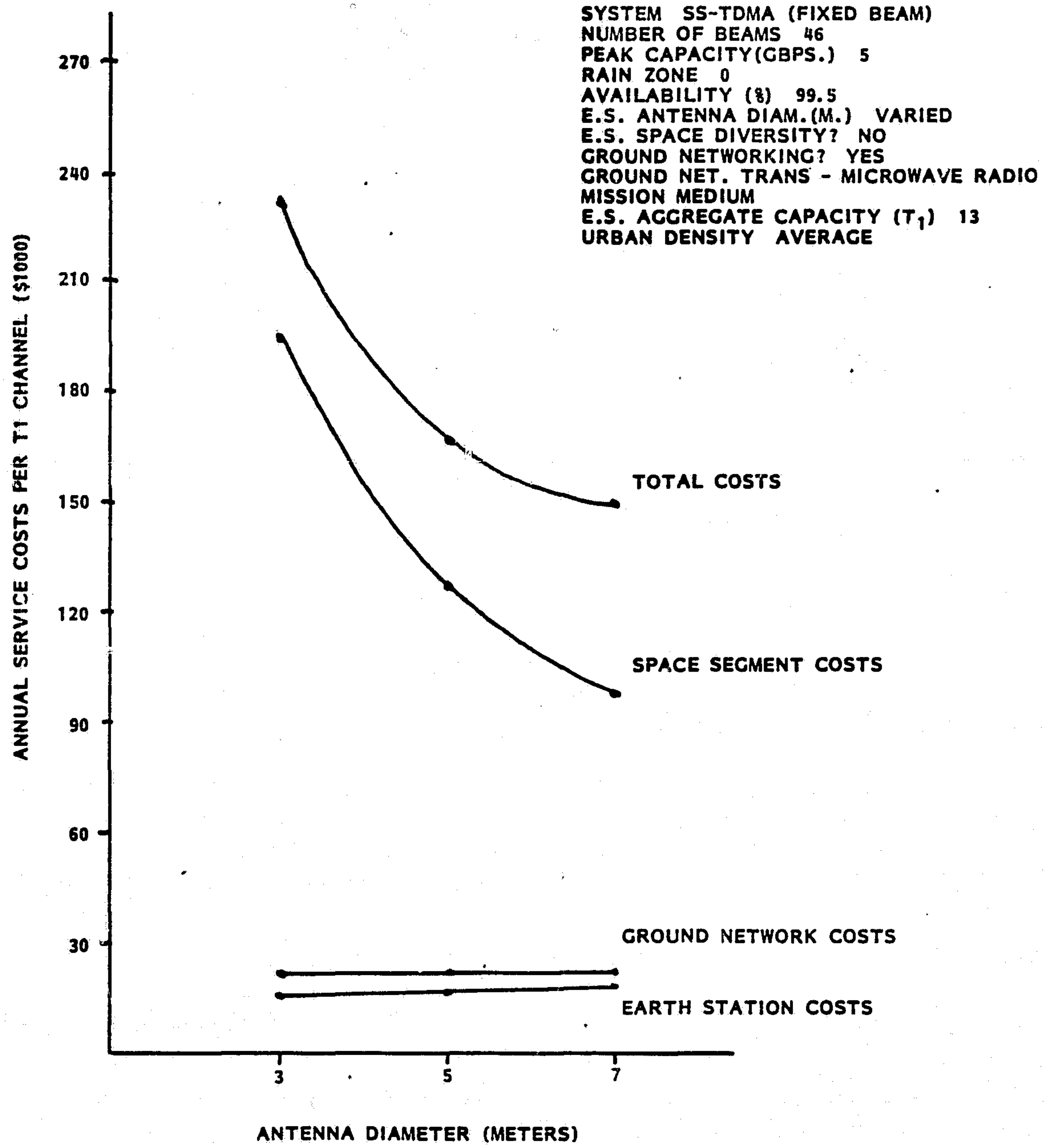

Figure 7.1-17. SS-TDMA/FB System 5 - Earth Station Antenna Diameter on Service Costs

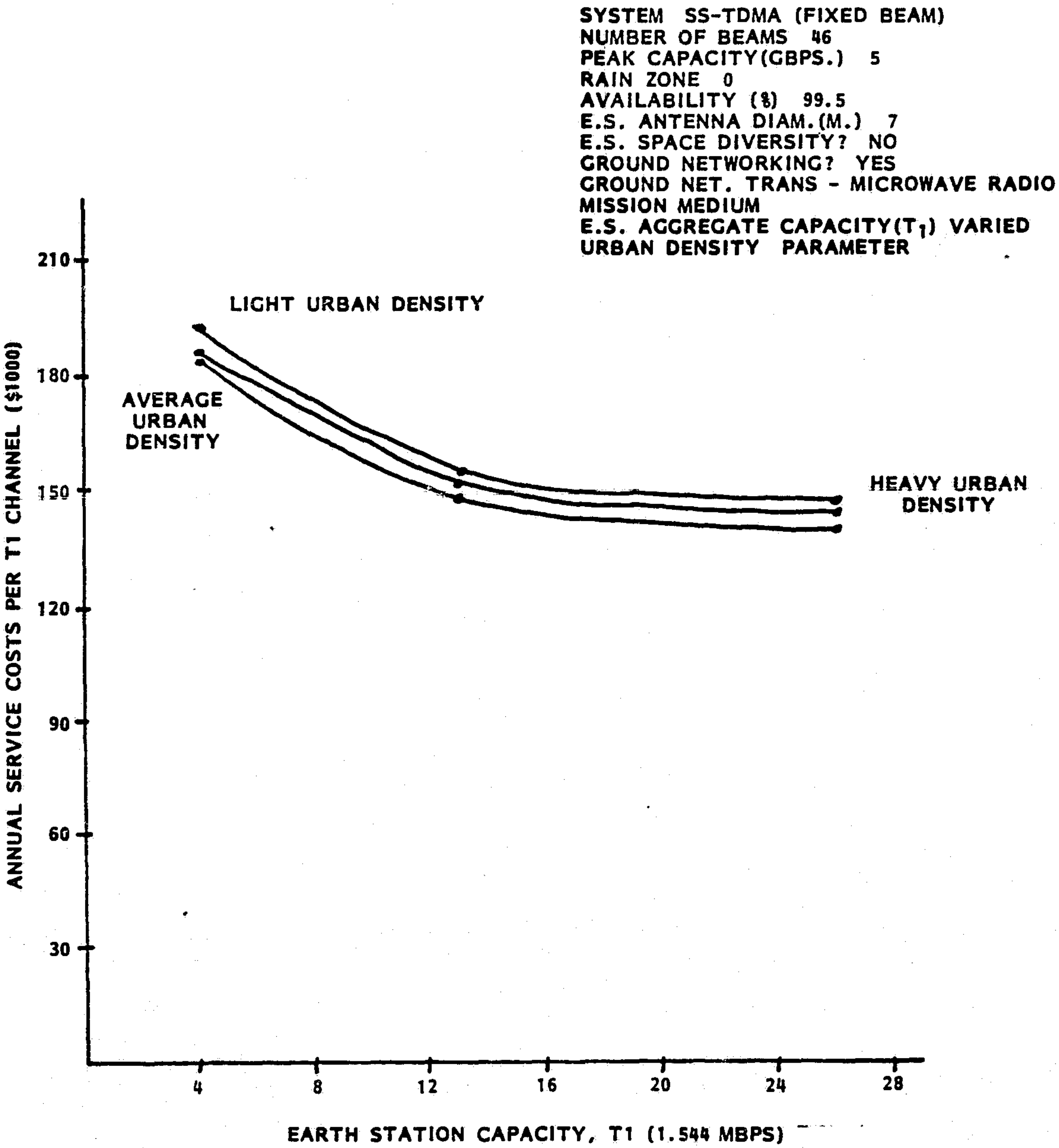

Figure 7.1-18. SS-TDMA/FB System 5 - Earth Station Capacity and Urban Density vs Service Costs

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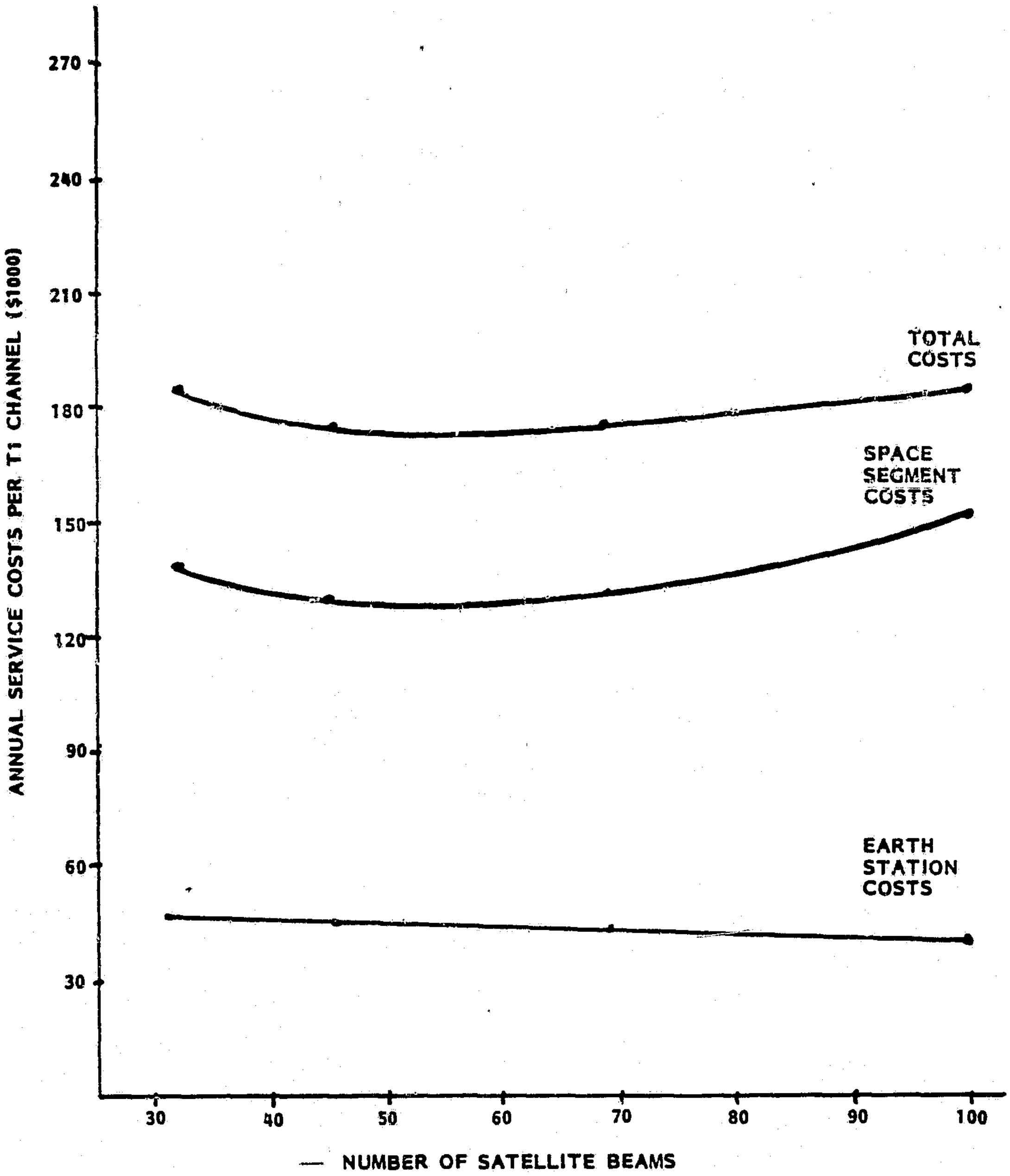

Figure 7.1-19. SS-TDMA/FB System 6 - Number of Satellite Beams vs Service Costs

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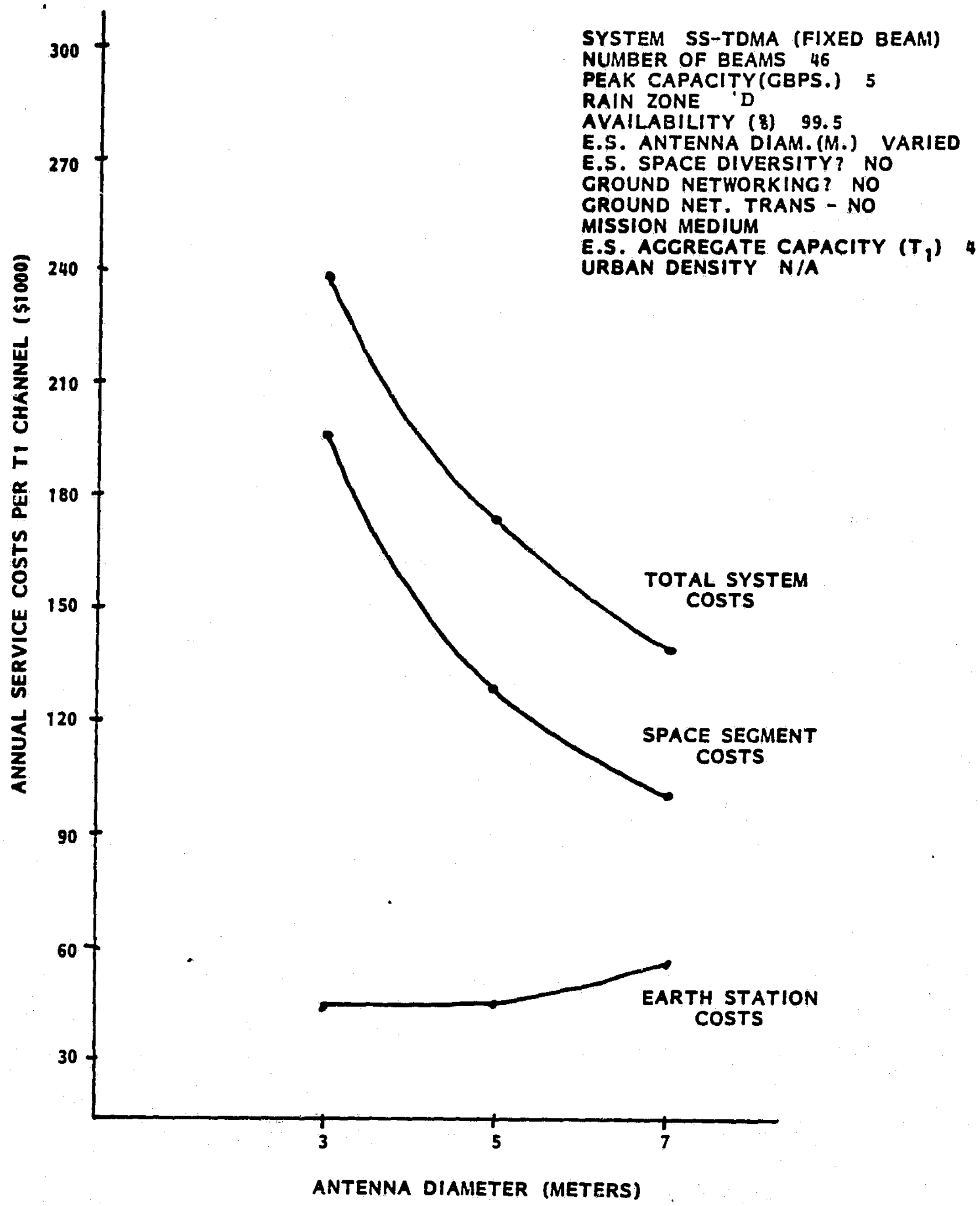

Figure 7.1-20. SS-TDMA/FB System 6 - Earth Station Antenna Diameter vs Service Costs

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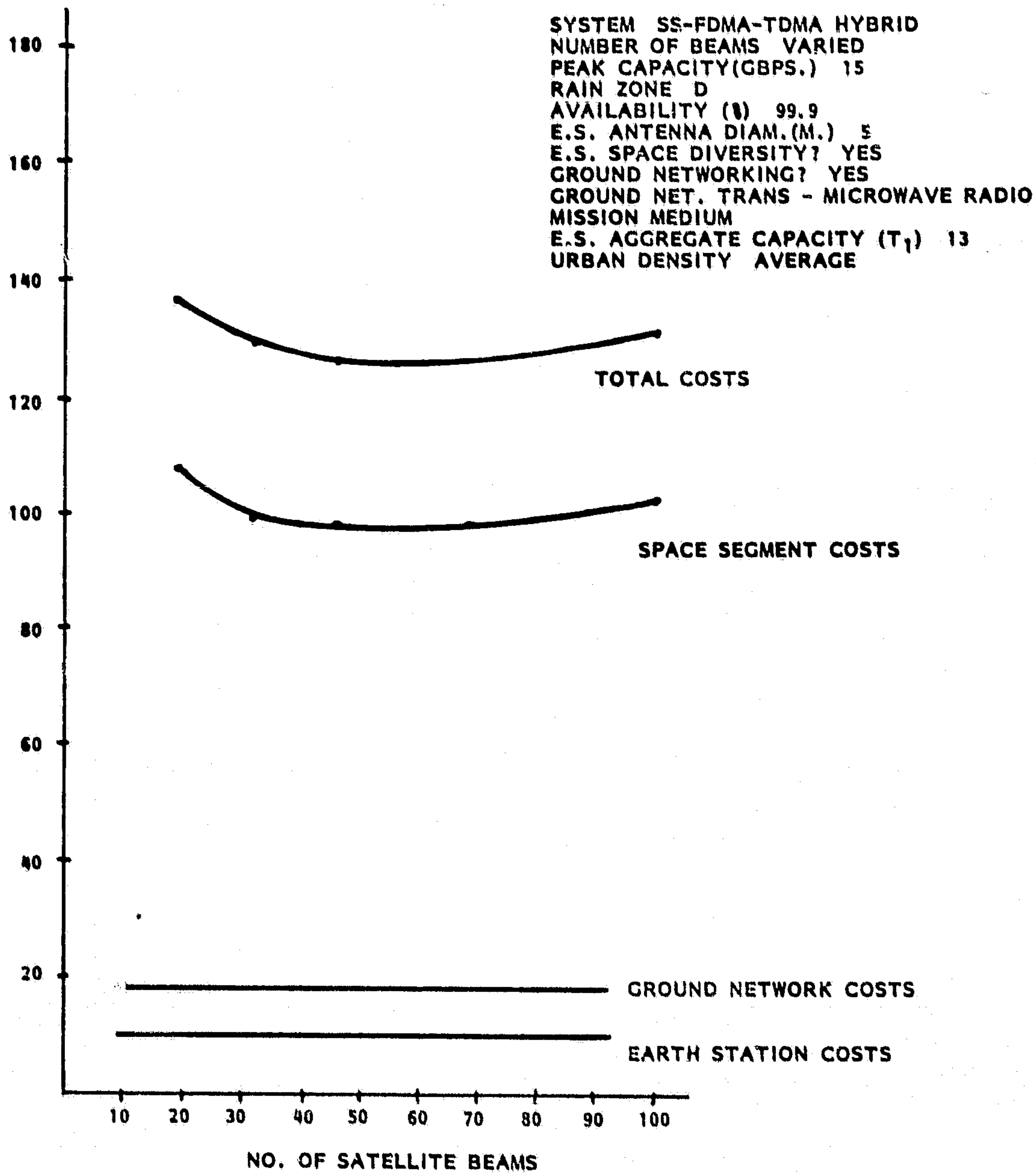

Figure 7.1-21. HYBRID System 1 - Number of Satellite Beams vs Service Costs

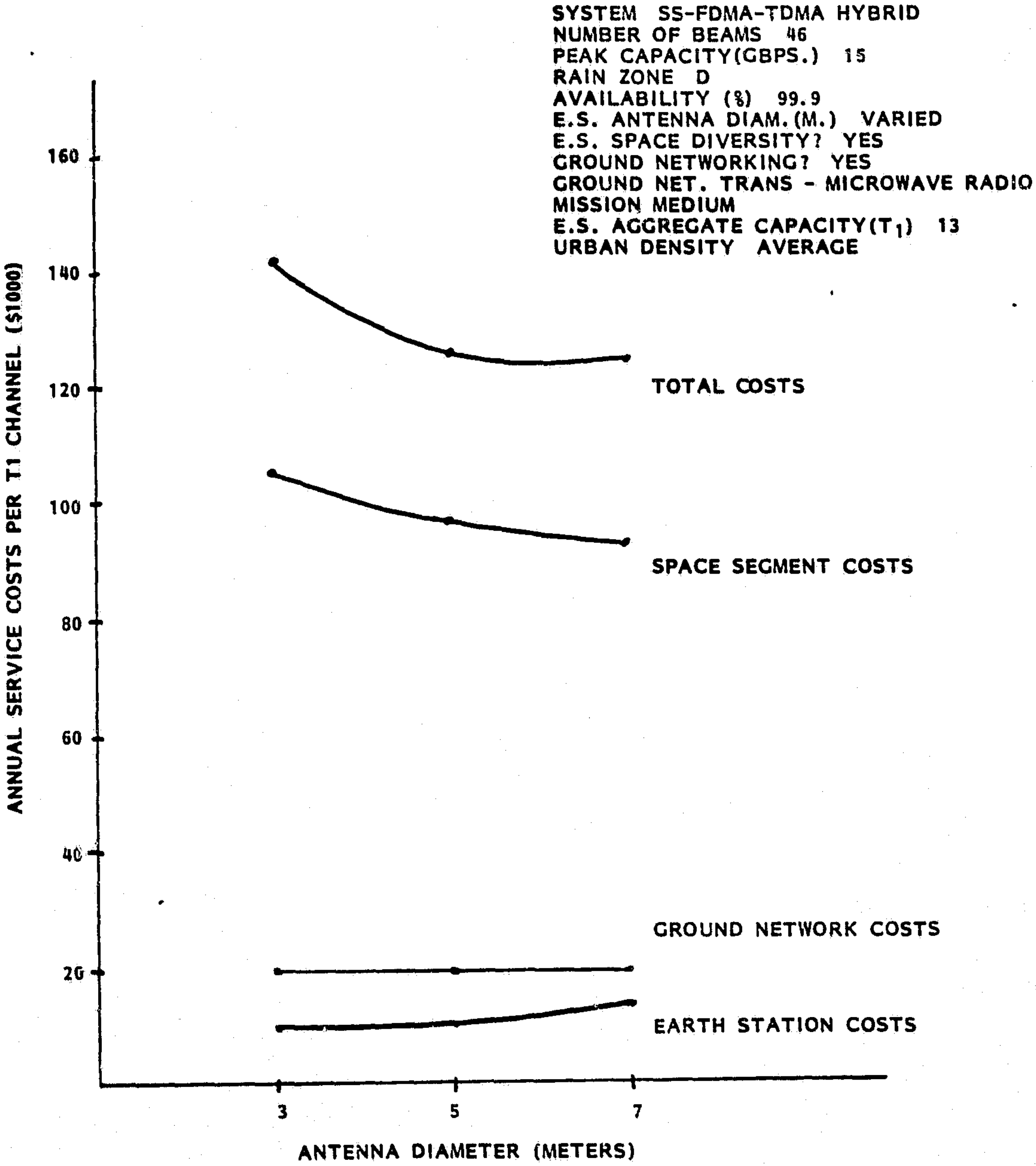

Figure 7.1-22. HYBRID System 1 - Earth Station Antenna Diameter vs Service Costs

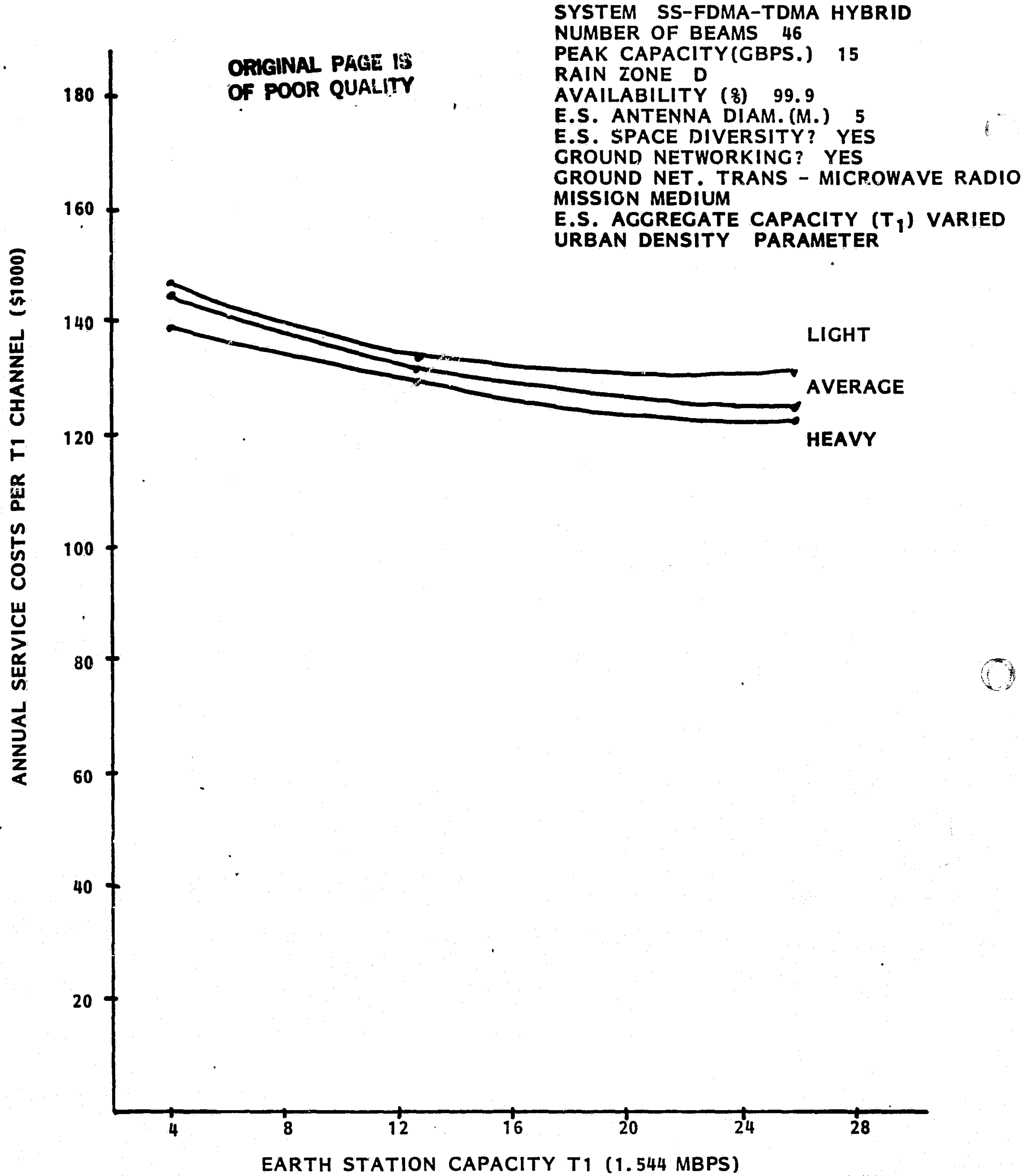

Figure 7.1-23. HYRBRID System 1 - Earth Station Capacity and Urban Density vs Service Costs

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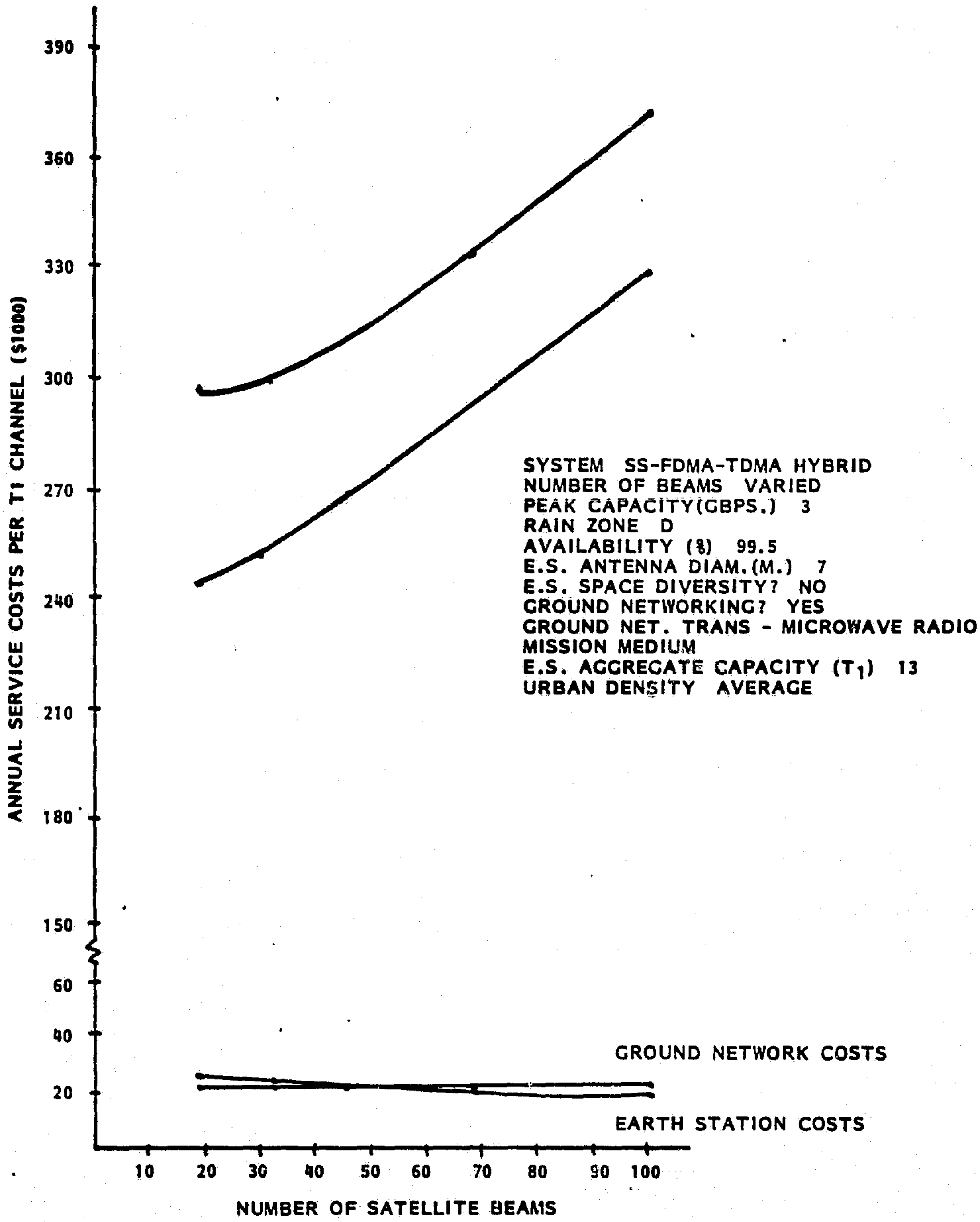

Figure 7.1-24. HYBRID System 2 - Number of Satellite Beams vs Service Costs

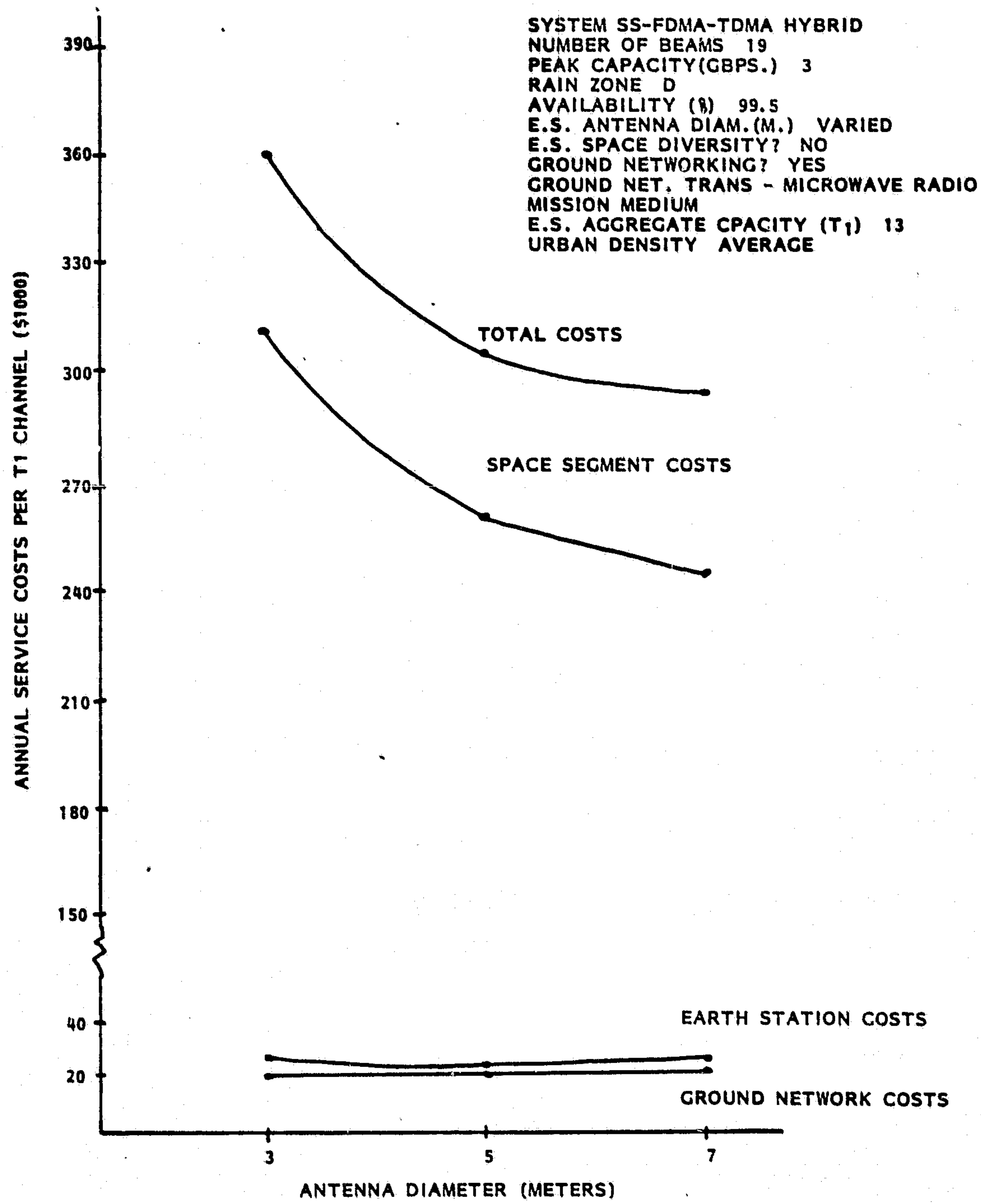

Figure 7.1-25. HYBRID System 2 - Earth Station Antenna Diameter vs Service Costs

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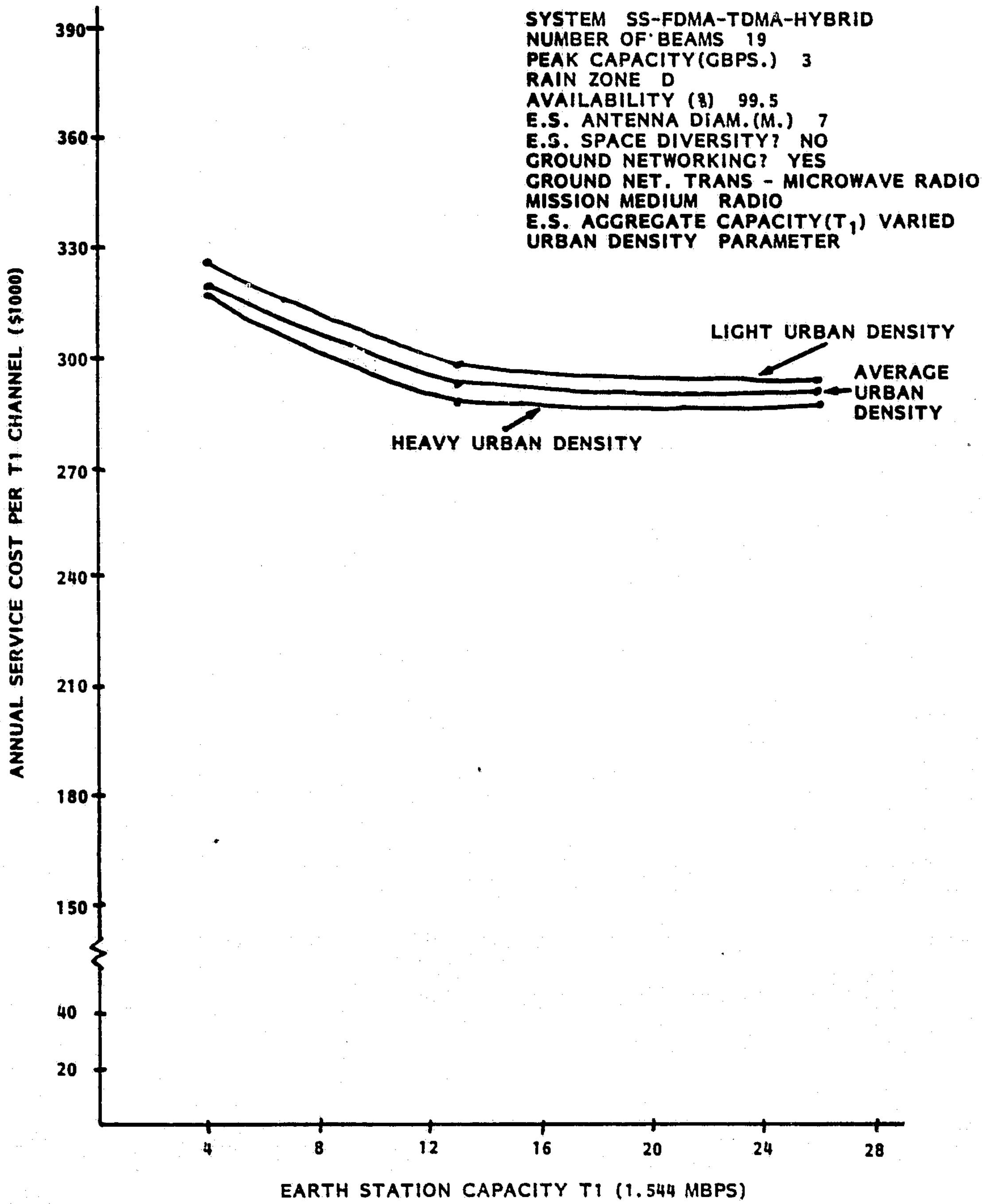

Figure 7.1-26. HYBRID System 2 - Earth Station Capacity and Urban Density vs Service Costs

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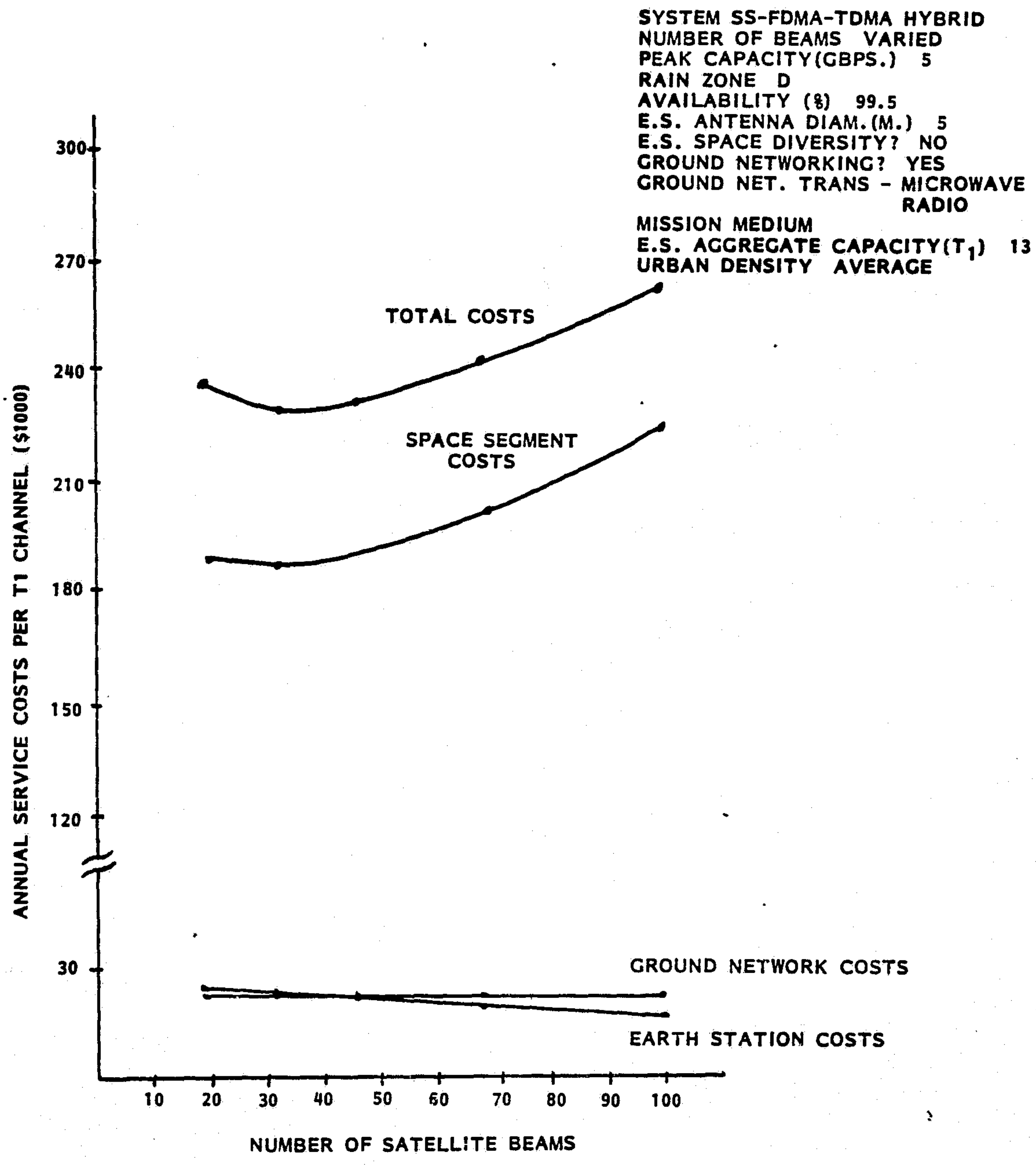

Figure 7.1-27. HYBRID System 3 - Number of Satellite Beams vs Service Costs

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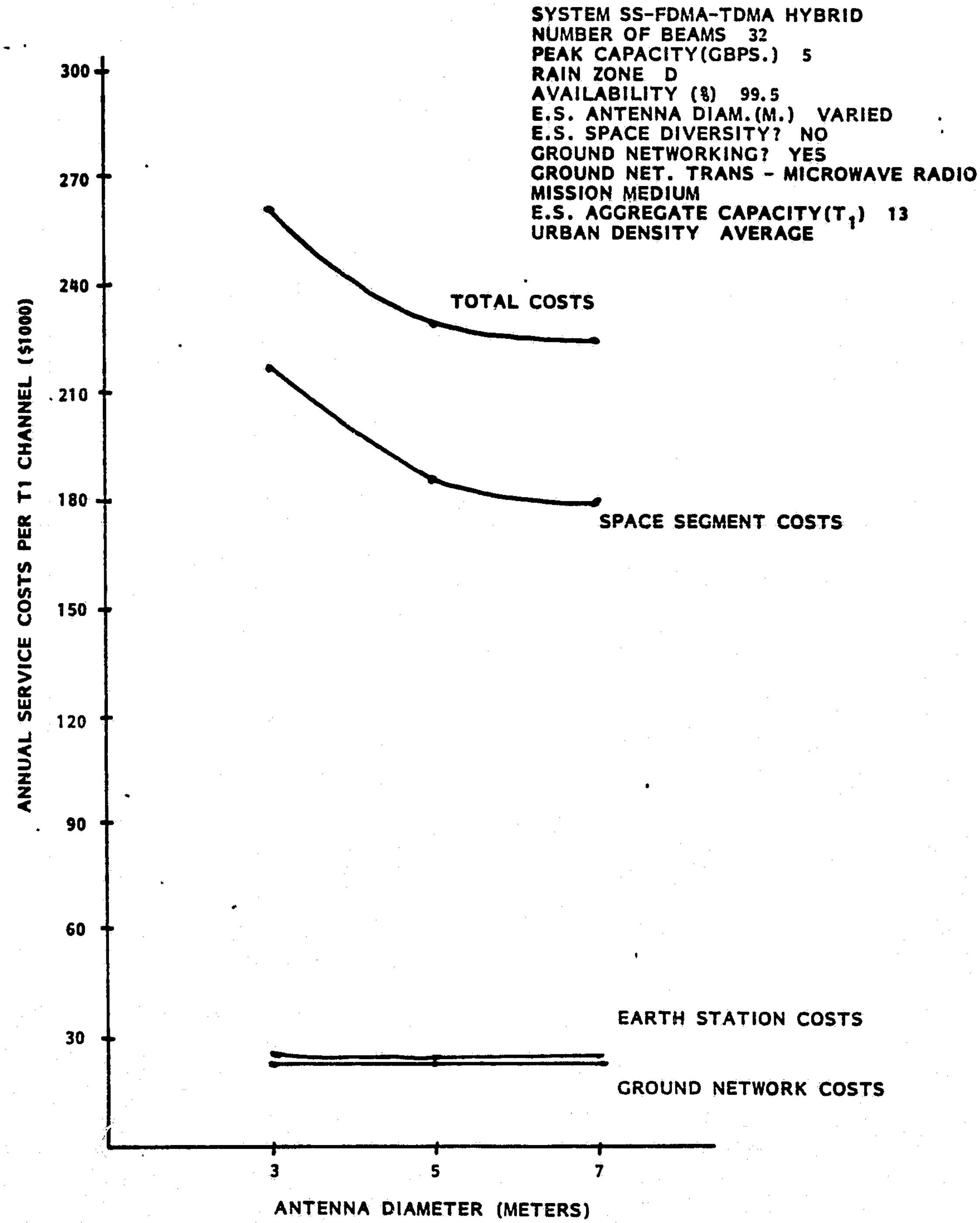

Figure 7.1-28. HYBRID System 3 - Earth Station Antenna Diameter vs Service Costs

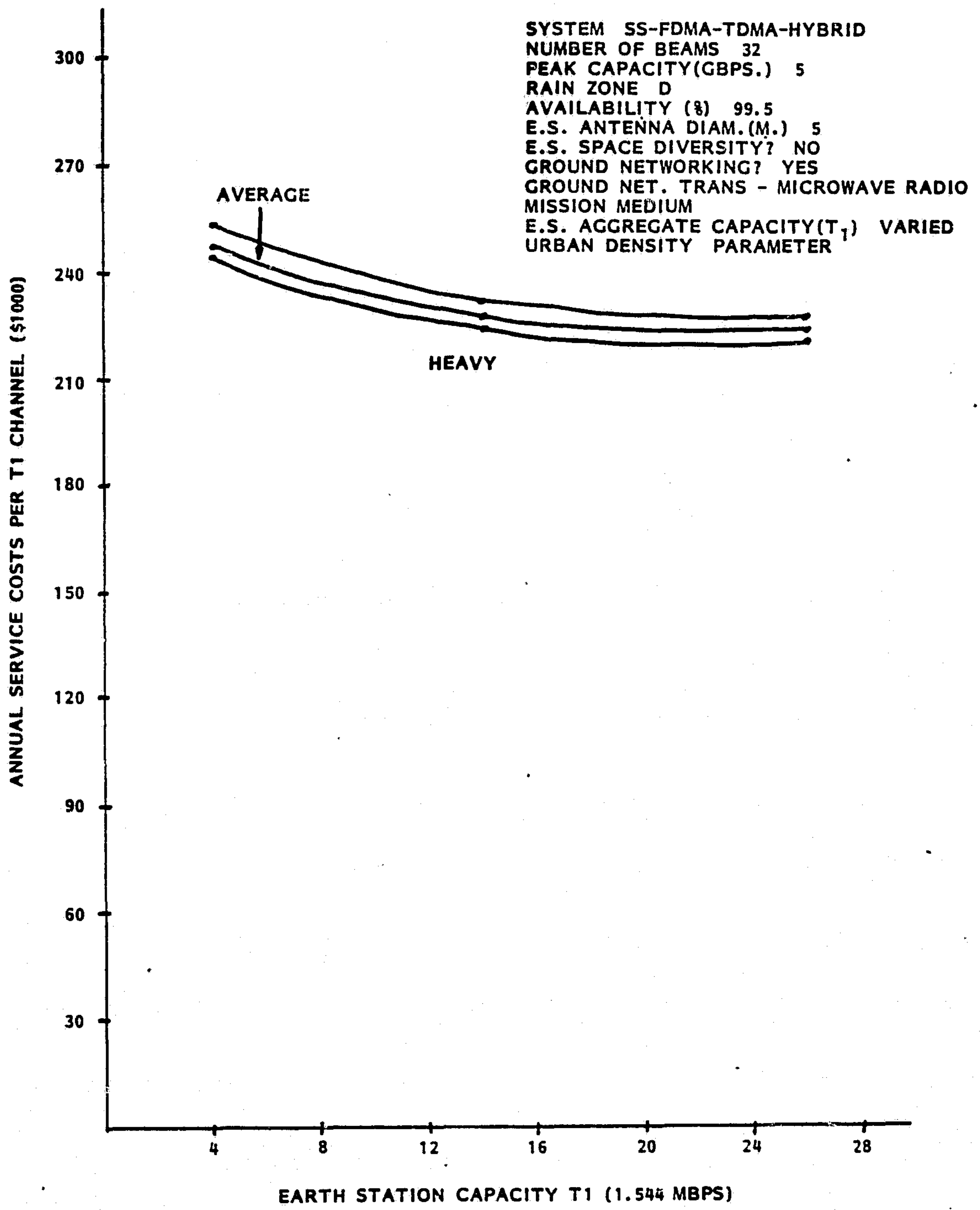

Figure 7.1-29. HYBRID System 3 - Earth Station Capacity and Urban Density vs Service Costs

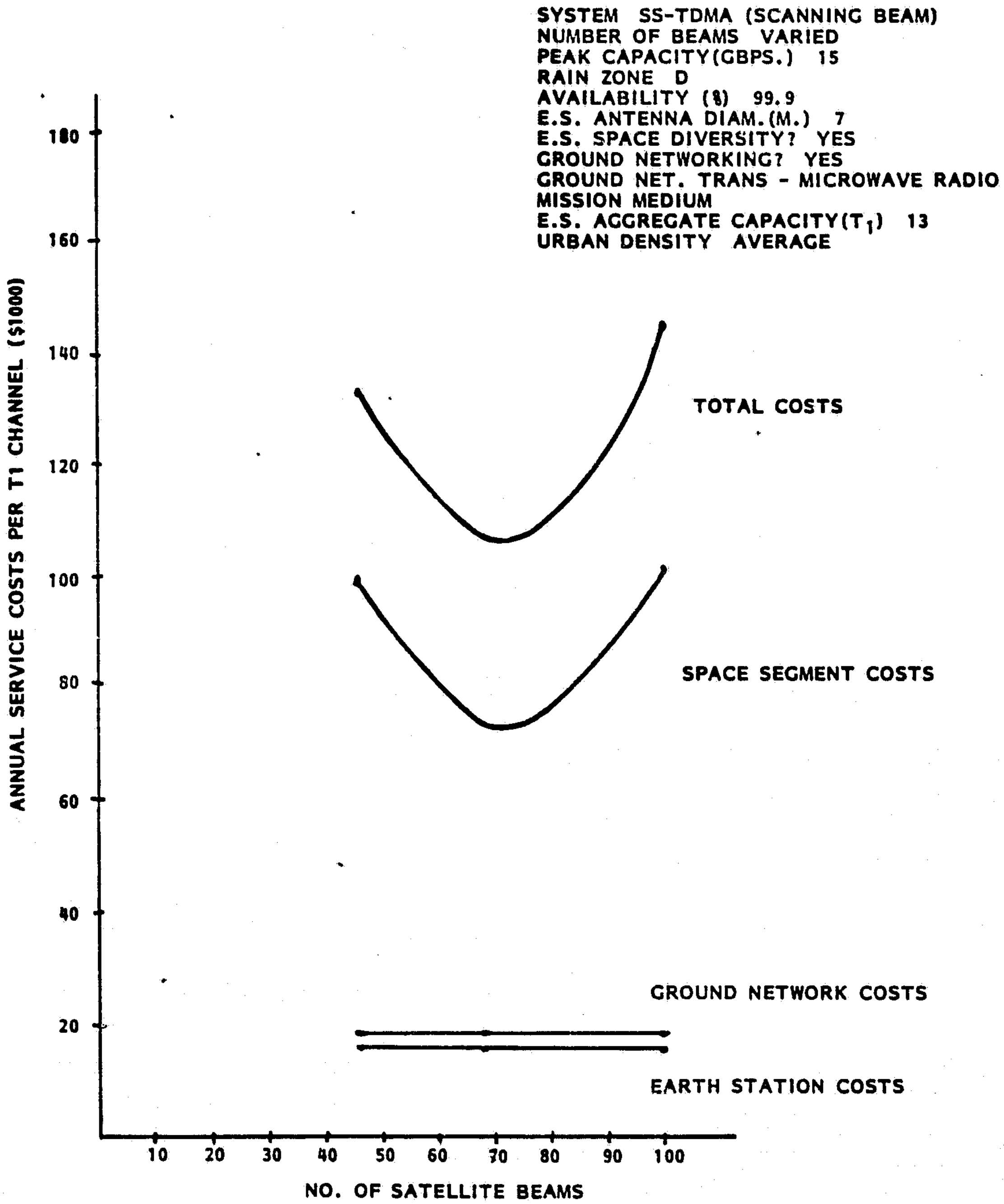

Figure 7.1-30. SS-TDMA/SV System 1 - Number of Satellite Beams vs Service Costs

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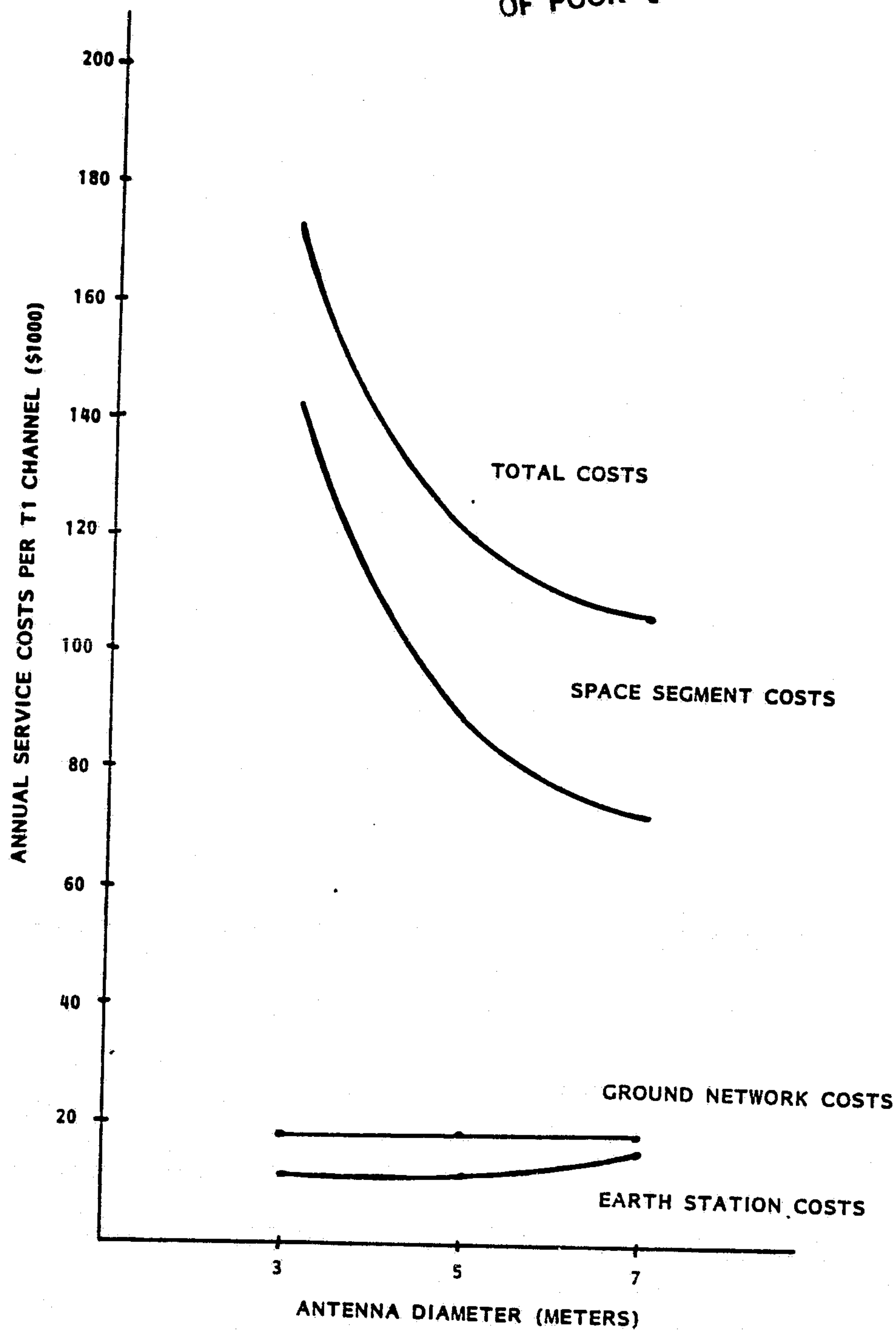

Figure 7.1-31. SS-TDMA/SB System 1 - Earth Station Antenna vs Service Costs

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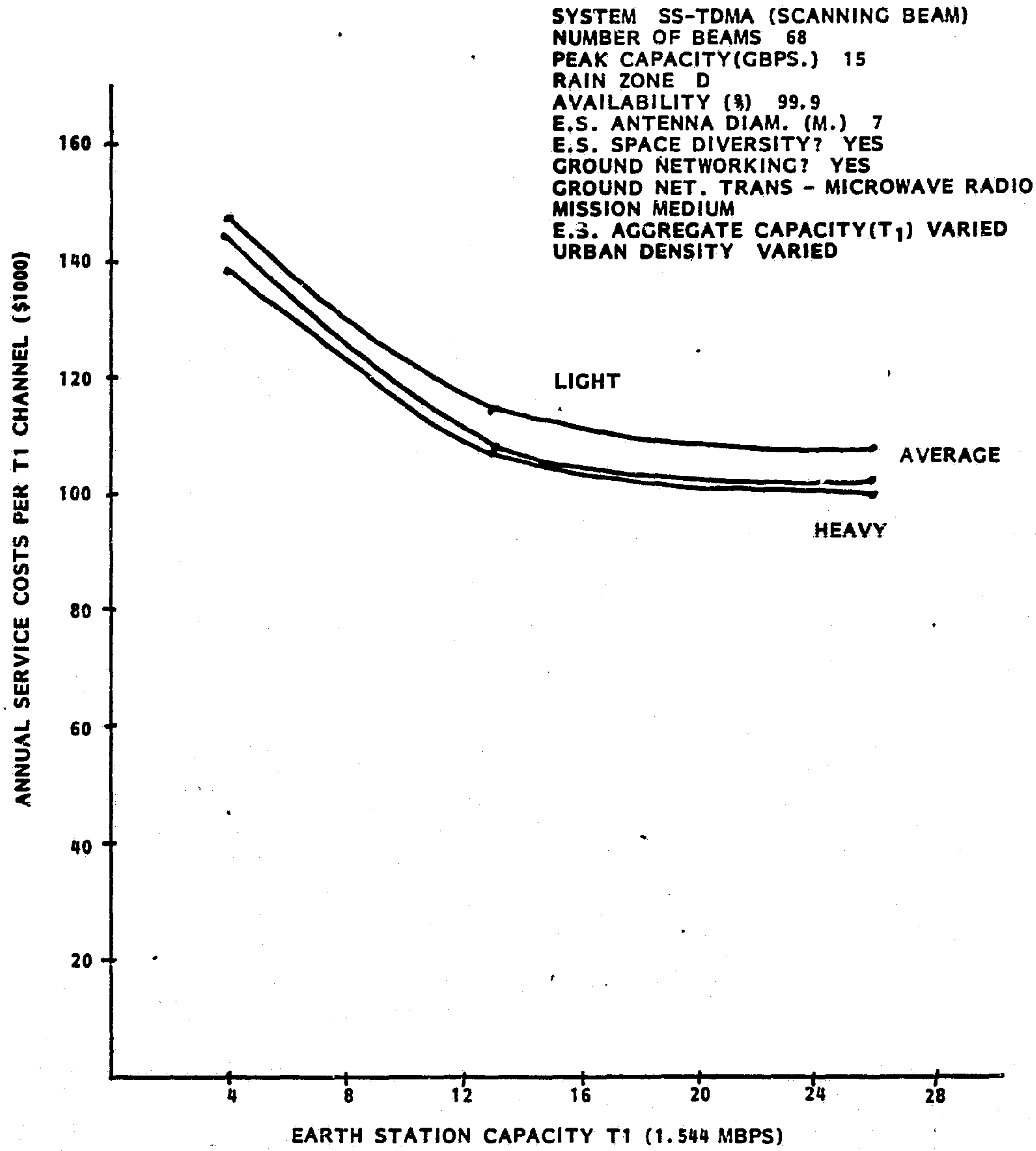

Figure 7.1-32. SS-TDMA/SB System 1 - Earth Station Capacity and Urban Density vs Service Costs

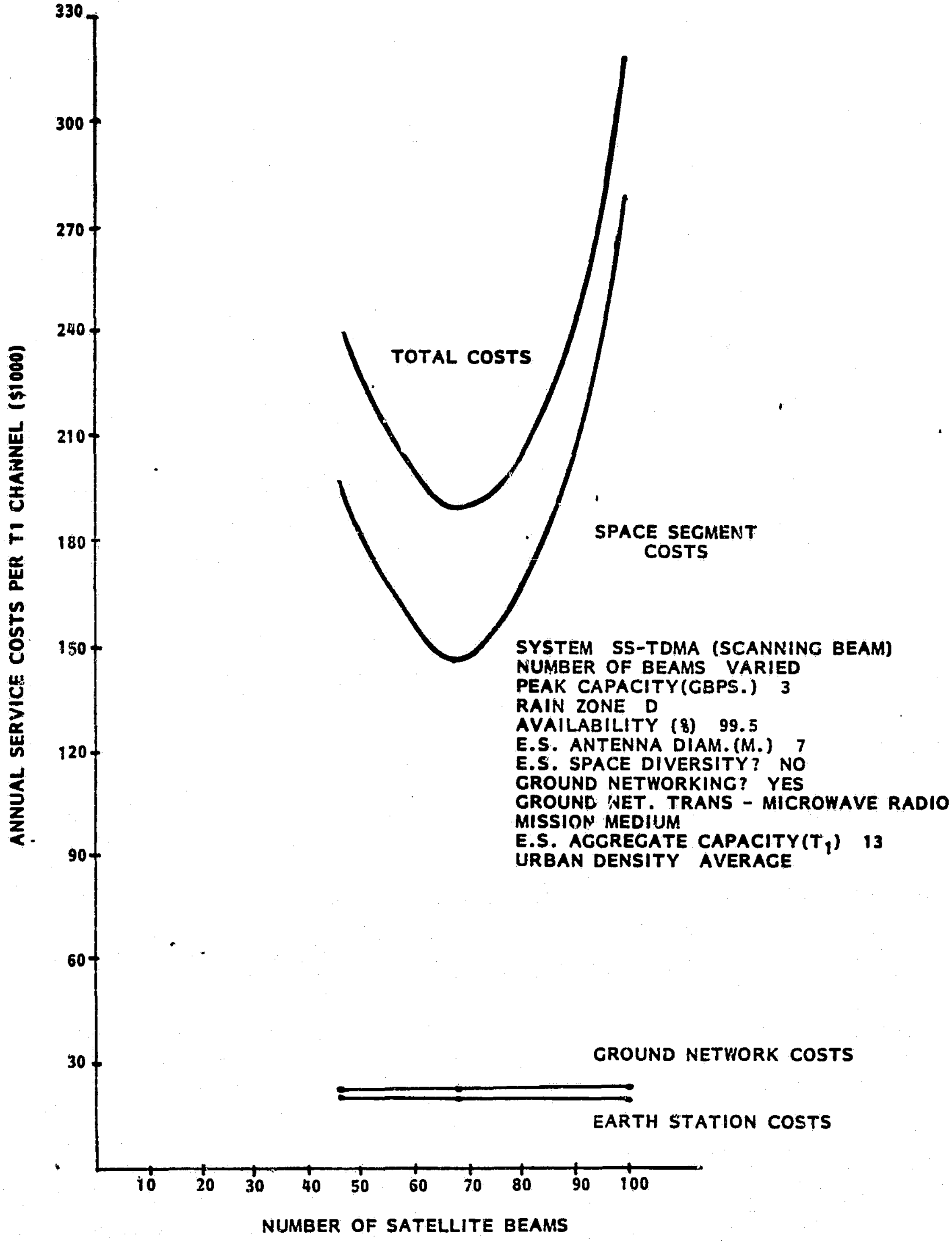

Figure 7.1-33. SS-TDMA/SB System 2 - Number of Satellite Beams vs Service Costs

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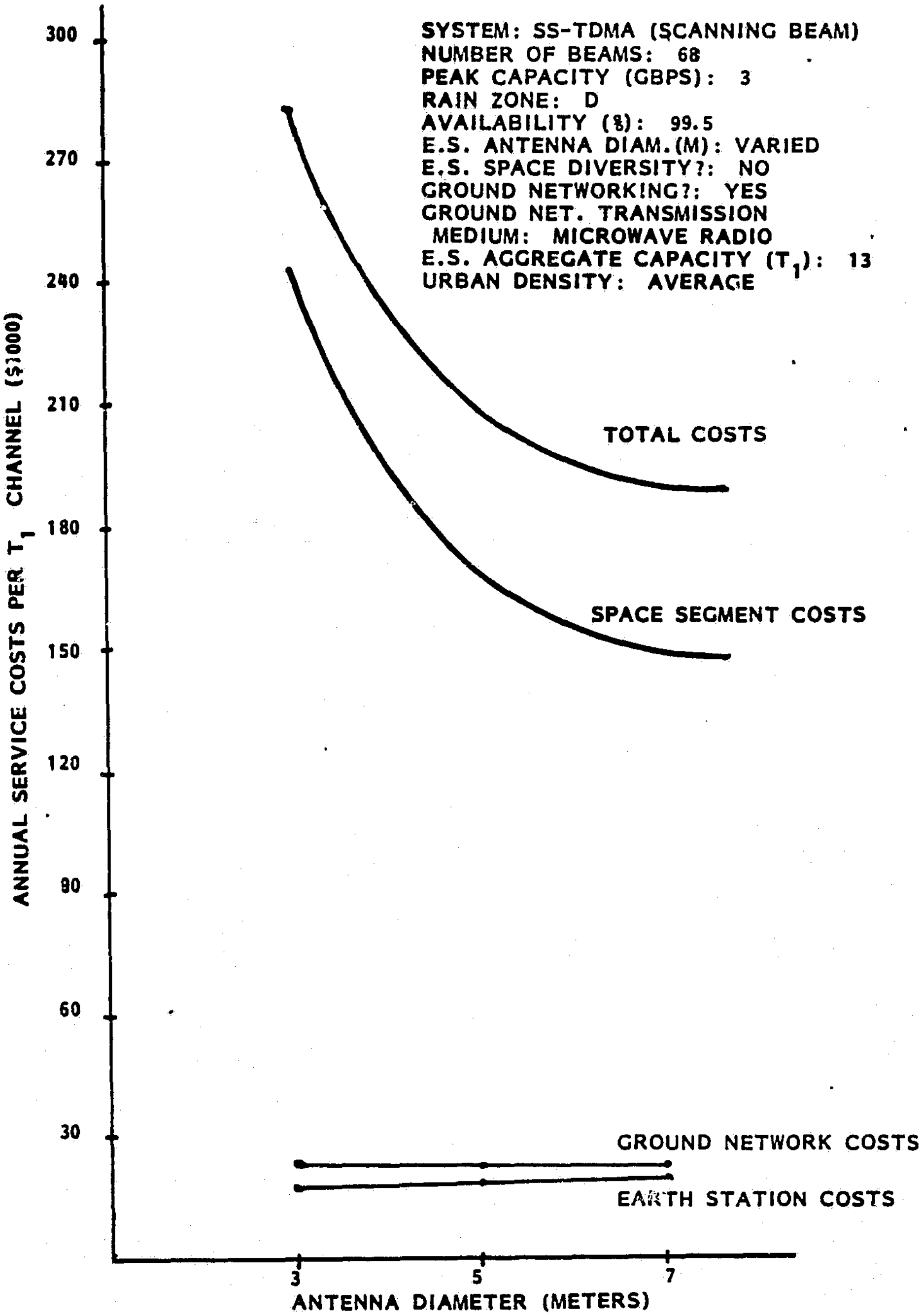

Figure 7.1-34. SS-TDMA/SB System 2 - Earth Station Antenna Diameter vs Service Costs

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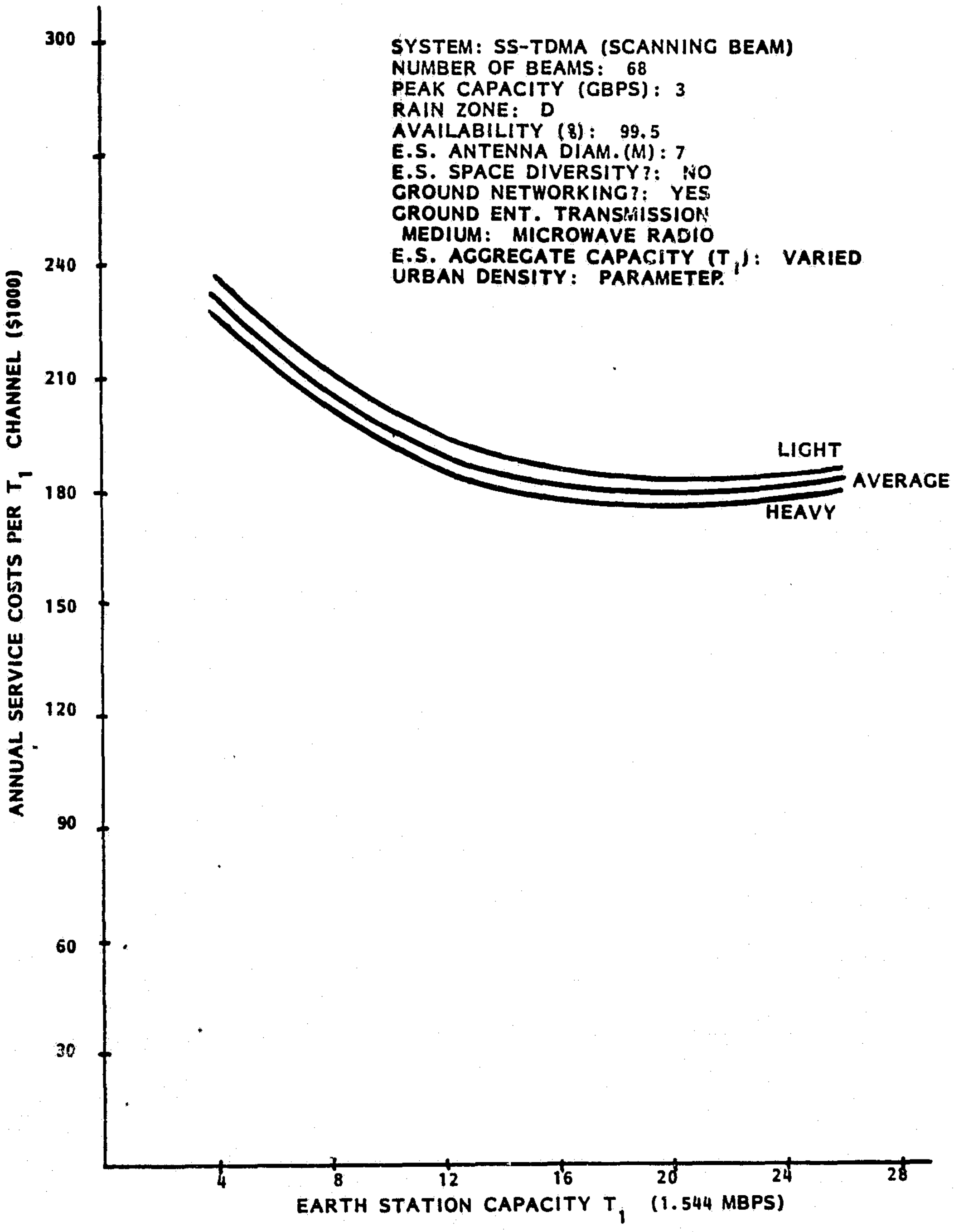

Figure 7.1-35. SS-TDMA/SB System 2 - Earth Station Capacity and Urban Density vs Service Costs

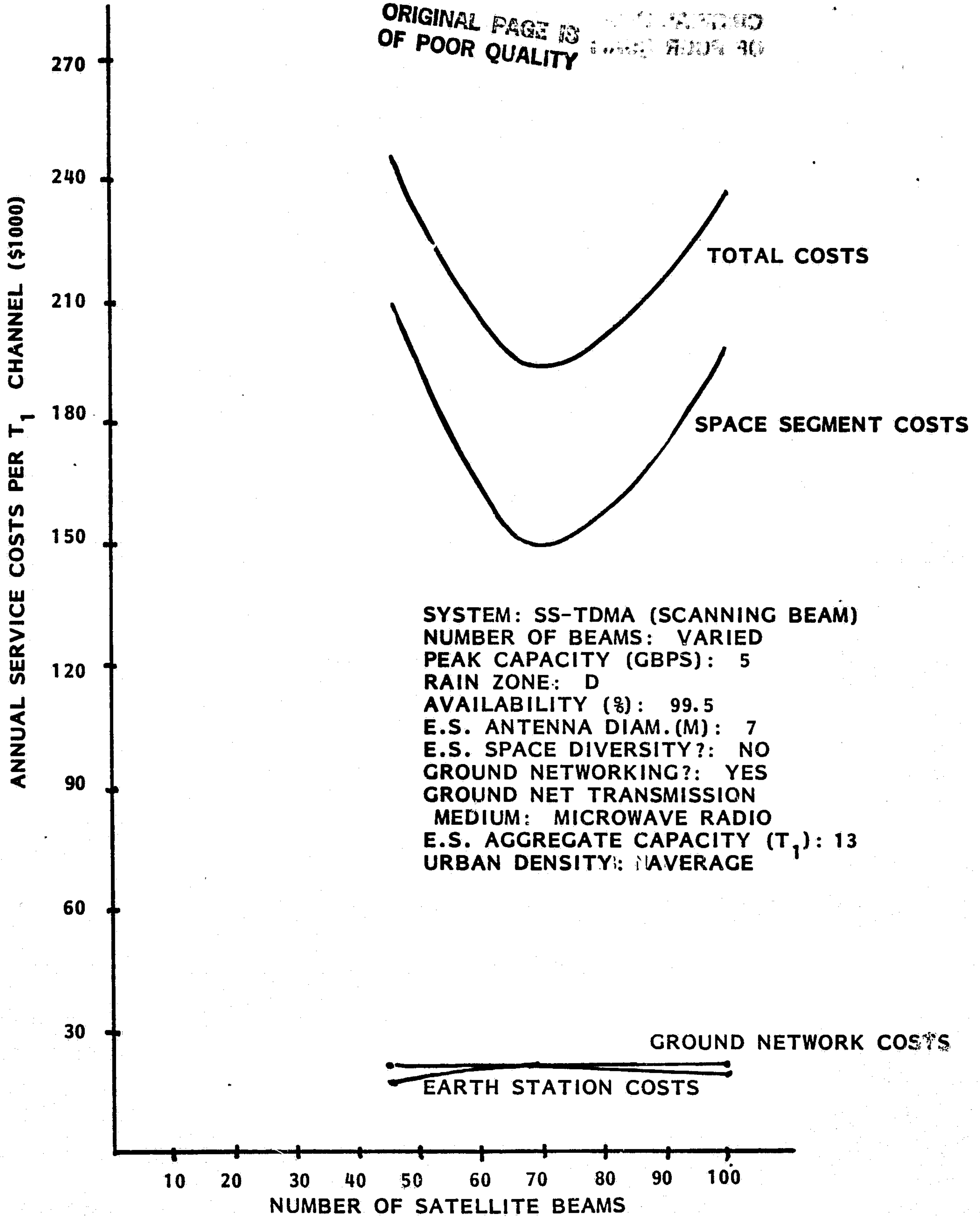

Figure 7.1-36. SS-TDMA/SB System 3 - Number of Satellite Beams vs Service Costs

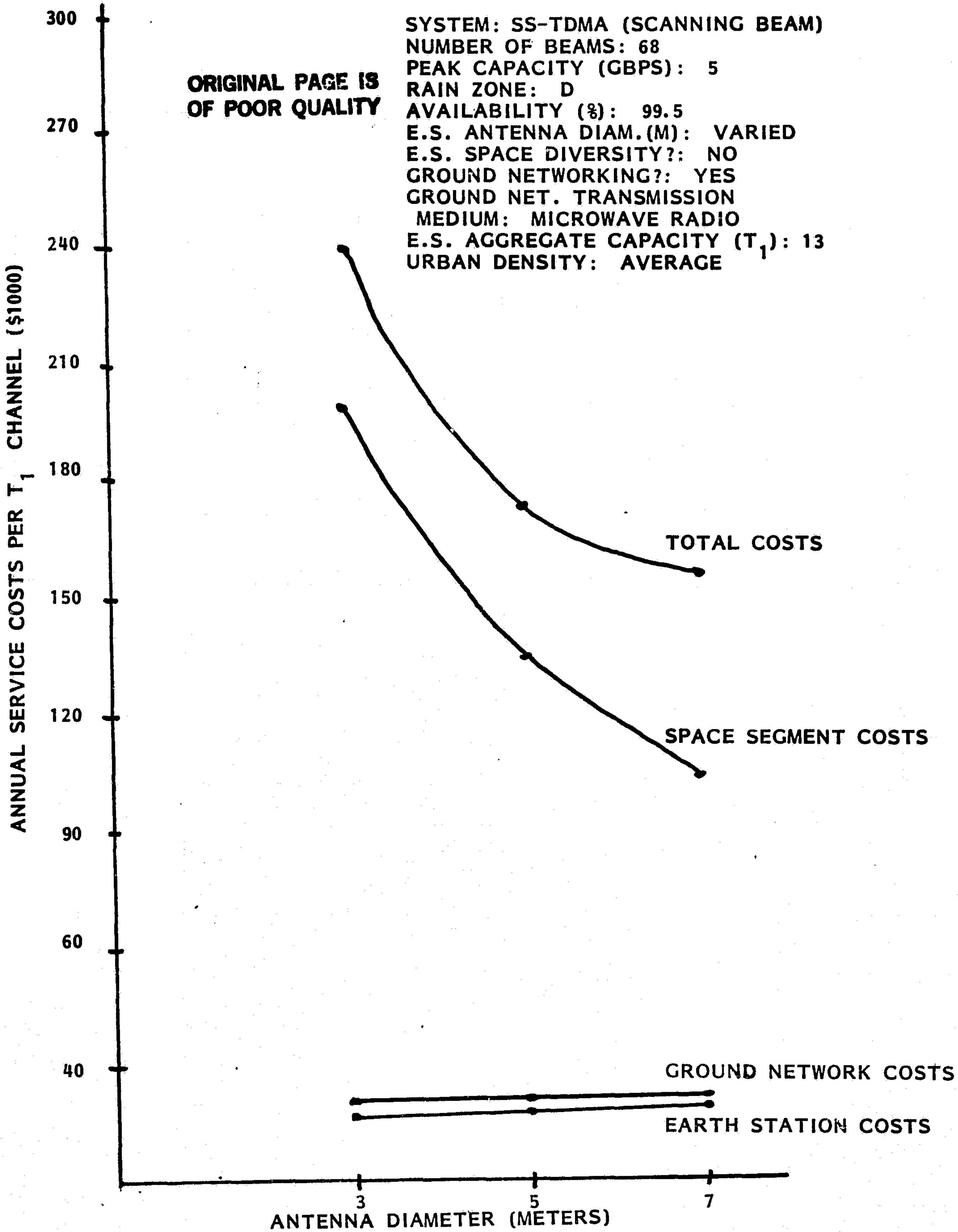

Figure 7.1-37. SS-TDMA/SB System 3 - Earth Station Antenna Diameter vs Service Costs

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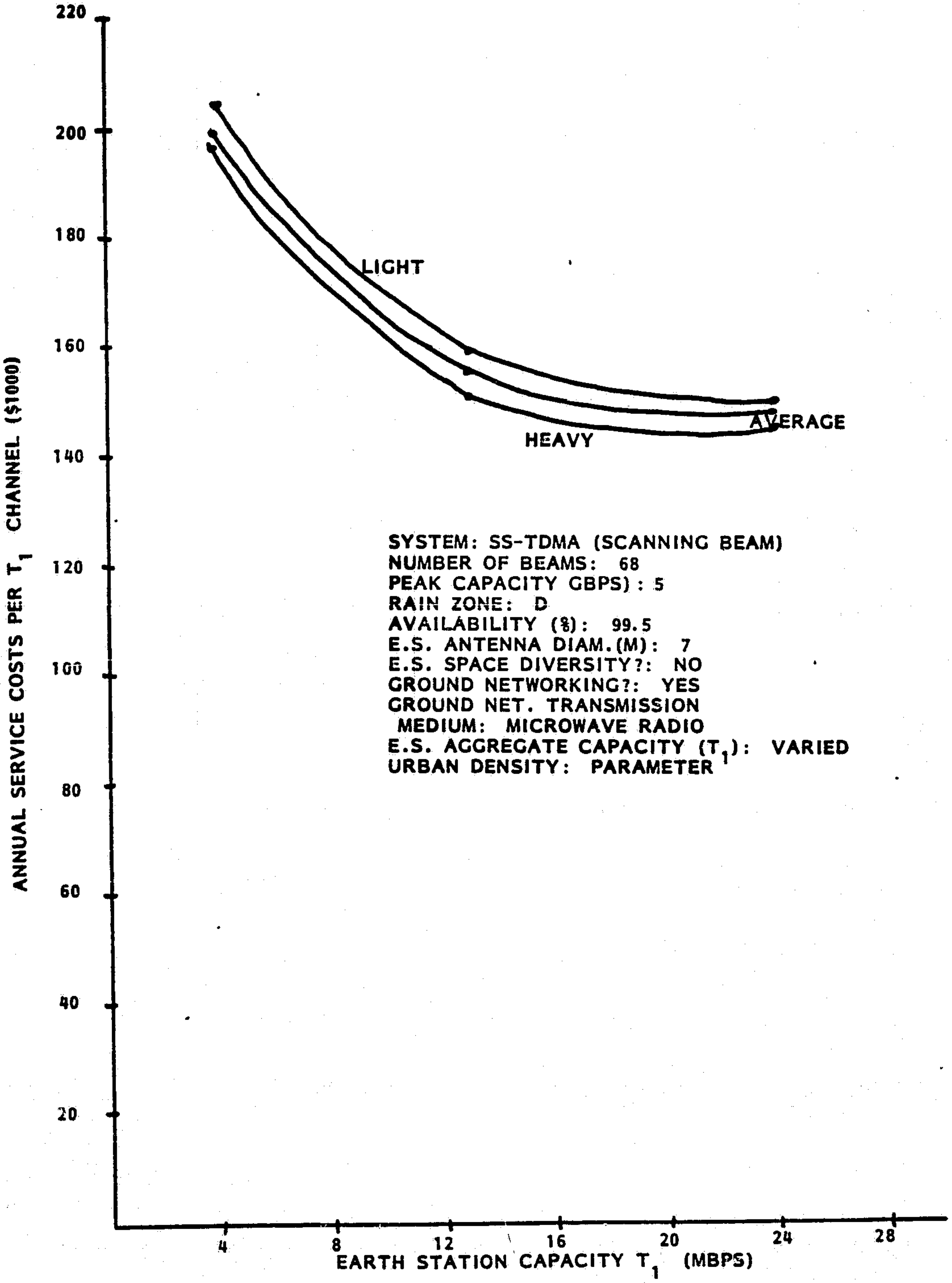

Figure 7.1-38. SS-TDMA/SB System 3 - Earth Station Capacity and Urban Density vs Service Costs

3. For the SS-FDMA, SS-TDMA/Fixed Beam and HYBRID systems a variation of the number of satellite beams from optimum has little influence on cost because of small effect on space segment weight. However, the reverse is true for the SS-TDMA/Scanning Beam system.

4. The effect of variation of urban density characteristics over a wide range (light to heavy) has much less influence on costs then the effect of reducing earth station capacity from 20 Mbps to a lower capacity.

The effect of other parameter variations such as availability and ground network transmission mode are also presented in this section. The above systems utilize data from rain zone D earth stations. However, comparison for costs averaged over the three regions based on relative capacity show less than one percent deviation from the D zone only costs.

A comparison of the minimum costs for each system versus capacity is given in Figure 7.1-39. These costs are for cases of optimum earth station antenna diameter (7 meter), earth station capacity of 20 Mbps (13T1), average urban area and microwave radio network for non-standalone systems. The 3/5 Gbps system assumes no diversity and an availability of 99.5% while the 15 Gbps systems use diversity and have 99.9% availability.

There are three additional SS-TDMA/Fixed Beam systems compared:

1. 3 Gbps standalone.
2. 5 Gbps standalone.
3. 15 Gbps diversity in E zone only.

The standalone systems use a group of three different size earth stations (1T1,, 4T1, 13T1) with the appropriate number assigned to each user group based on Section 2.3 data and the proportion in each rain zone based on relative traffic in these zones. The 15 Gbps system with diversity in E zone only is one approach in which diversity need not be employed in major sections of CONUS and yet achieve a goal of 99.9% availability with competitive costs. If diversity is too difficult to achieve, the 99.9% availability is still achievable in rain zones D and B (C,F) which provides coverage for 88 percent of CONUS's capacity. However, the availability in rain zone E (the remaining 12% of CONUS's capacity) must be reduced to less than 99.5%.

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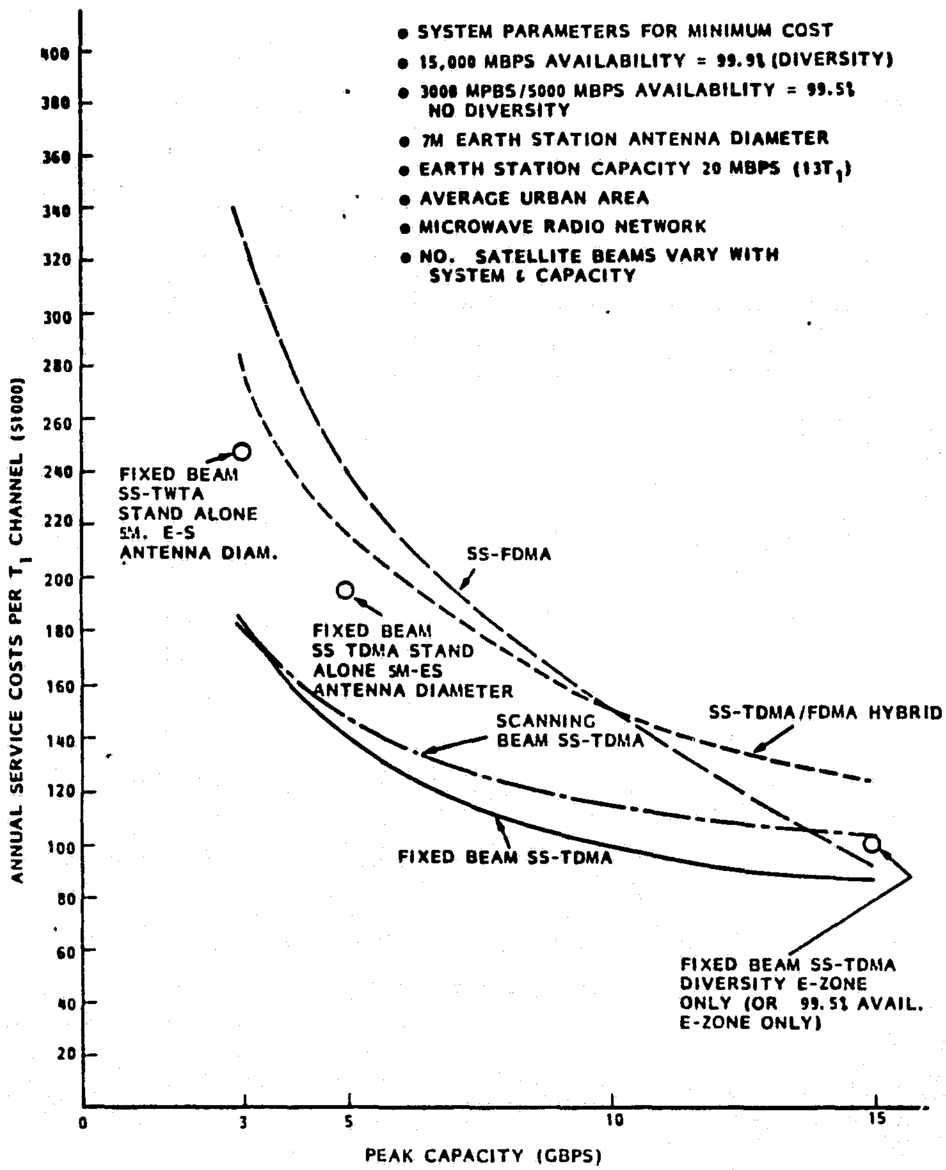

Figure 7.1-39. System Service Charges Per T_1 vs Peak Capacity

The overall conclusion is that the fixed-beam SS-TDMA system approaches minimum costs for all availabilities and capacities in the range of 3 Gbps to 15 Gbps (except for 3 Gbps where the scanning beam TDMA offers a slight cost advantage). The SS-FDMA shows considerable disadvantage for non-diversity cases because of the much higher EIRP's especially at an availability of 99.9%. For the 15 Gbps system, the SS-TDMA/Fixed Beam system has only about a 10% less cost than the SS-FDMA system. The HYBRID offers no cost advantage at any capacities. The SS-TDMA/Scanning Beam system gives comparable or lower costs when compared the SS-TDMA/Fixed Beam system at capacities less than 4 Gbps.

The standalone systems result in considerable cost penalty because of the high earth station costs. In an integrated system, the majority of the systems in the urban areas would use networked interconnections while only a smaller percentage of the systems in the lower density areas would be standalone. This would drive the costs toward the network case with the usage of large earth stations for most of the system capacity.

7.1.2 CHARACTERISTICS OF SELECT CPS SYSTEMS

Of the systems analized in Section 7.1.1, eight of these will be examined in more detail. The design conditions will be primarily in the range for minimum cost performance, cover all capacities, networking and standalone and diversity or non-diversity. These are systems one through seven and system twelve of Section 7.1.1. The cost assumptions of Table 7.1-2 are utilized.

SS-FDMA 15 Gbps System

A summary of the system design and cost characteristics are given in Table 7.1-3 for the 15 Gbps SS-FDMA system. For larger capacity systems, the ground segment results in the greater portion of the initial investment. For the SS-FDMA, 53.3% of the initial investment is from the ground segment. Table 7.1-4 gives a summary of the total annual charges for each user group facility with a breakdown by traffic service indicated. Based on the data of Table 7.1-4 and Section 2.3, the unit service charges are given in Table 7.1-5 assuming a 40 hour service week.

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Table 7.1-3. SS-FDMA System Characteristics

- Peak Aggregate Capacity 15 Gbps
- 99.9% availability

1. System Description
   - Ground Segment: 750 earth stations of 20 Mbps (13T1) peak capacity each
     - Antenna Diameter - 7 meters
     - Microwave Radio Networking
     - Earth Station Space Diversity
     - Facility Density: Average Urban Area
   - Space Segment: 68 Beam Coverage
     - Payload Weight - 2185 lbs.
     - Payload Power - 7022 watts

2. Installed Costs

- Total Space Segment	$ 518.9 million
- Earth Station	$ 223.4 million
- Ground Network	$ 368.5 million
TOTAL SYSTEM	$1,110.8 million

- Installed Cost of Earth Station - $297,808
- Installed Network Costs per $491,350 earth station (including diversity)

3. Annual Service Charges

- Space Segment	$ 622.6 million
- Earth Station	$ 132 million
- Ground Network	$ 180 million
TOTAL	$ 934.6 million

Table 7.1-4. Total Annual Charges Vs. Class/Traffic Service ($1000) per facility

FDMA SYSTEM
AVAILABILITY=>99.9%

USER CLASS	VOICE	VIDEO CONF.	VIDEO INFO. SERV.	DATA MESS.	DATA COMPUT.	TOTAL USER
LARGE BUSINESS	188.04	202.26	0.00	10.96	15.75	417.04
SMALL BUSINESS	31.10	0.00	0.00	3.80	3.54	38.44
GOV. AGENCIES	276.76	200.40	400.88	18.15	31.13	927.34
MUNICIPALITIES	31.40	0.00	0.00	3.80	3.26	38.44
INSTITUTIONS	74.97	194.07	388.23	10.56	15.09	682.94
HOMES AND CONDOS	199.39	0.00	384.83	0.00	5.98	590.70

THE TOTAL COST PER T1 LINE IS =96139.8
SPACE SEGMENT CONTRIBUTION=64091.2
GROUND NETWORK CONTRIBUTION=18493.4
EARTH STA SEGMENT CONTRIBUTION=13555.2

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Table 7.1-5. Unit Service Charges - SS-FDMA System

User Class	Voice $/Call-Hr	Video Conf. $/Conf-Hr.	Video Info. $/Hour	Data Message $/56Kbps-Hr	Data Computer $/9.6Kbps-Hr
Large Business	1.81	97.24	0	1.76	.30
Small Business	1.87	0	0	1.83	.34
Government Agencies	1.75	96.35	192.73	1.75	.30
Municipalities	1.87	0	0	1.83	.34
Institutions	1.80	93.30	186.65	1.69	.92
Homes and Condos	1.92	0	185.01	0	.29

+40 Hour Week (2080 Hours/Year)

The effect of change of system parameters on cost is given in Table 7.1-6. The performance of the SS-FDMA is strongly dependent on diversity. For example, if the availability is reduced to 99.5% and diversity is eliminated, the system costs increase by more than 200%.

Table 7.1-6. SS-FDMA System Effect of Change of System Parameters on Total Service Charges

• Space Segment Parameters	
Reduce Beams to 46	+4%
Increase Beams to 100	+2%
• Earth Station	
Reduce Antenna Diameter to 5M	+9.3%
Reduce Capacity to 4T1	+27.8%
Increase Capacity to 26T1	-3.6%
• Ground Network	
In a High Density Urban Area	-.6%
In a Low Density Urban Area	+7.1%
Use of Coaxial Cable	+4.4%
Use of Fiberoptics	+15.7%
• Eliminate Station Space Diversity and Reduce Availability to 99.5%	+208%

SS-TDMA/Fixed Beam 15 Gbps System

A summary of the system design and cost characteristics are given in Table 7.1-7 for the 15 Gbps SS-TDMA system. This particular system results in the minimum service charges of all the systems analyzed. Table 7.1-8 presents the annual charges per user group facility and Table 7.1-9 gives the

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corresponding unit service charges. The effect of change of system parameters on cost is given in Table 7.1-10. The SS-TDMA/Fixed Beam System is very flexible in that low cost performance is possible without diversity. For example, if diversity is eliminated and the availability is reduced to 99.5%, the costs are about the same, however, if the availability is increased to 99.9% with the elimination of diversity, the costs increase by more than ten-fold. It is possible to eliminate diversity from all regions except the E-zone and still provide service with competitive costs. This is discussed in Section 7.1.2.

Table 7.1-7. SS-TDMA/Fixed Beam System 1 Characteristics

- Peak aggregate capacity 15 Gbps
- 99.9% availability
- Fixed Beam

1. System Description
   - Ground Segment: 750 Earth Stations of 20 Mbps (13T1) peak capacity each
     - Burst Rate - 128 Mbps
     - Antenna Diameter - 7 meters
     - Multiearth Station Space Diversity
     - Microwave Radio Networking
     - Facility Density: Average Urban Area
   - Space Segment: 68 Beam Coverage
     - Payload Weight - 1812 lbs.
     - Payload Power - 4856 watts

2. Installed Costs
   - Total

Space Segment	$ 444.2 million
Earth Station	$ 208 million
Ground Network	$ 368.5 million
TOTAL SYSTEM	$1,020.7 million

   - Installed Cost of Earth Station - $277,300
   - Installed Network Costs-$491,350
     Per Earth Station (including diversity)

3. Annual Service Charges

- Space Segment	$ 533.1 million
- Earth Station	$ 122.6 million
- Ground Network	$ 180 million
TOTAL	$ 835.7 million

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Table 7.1-8. Total Annual Charges Vs. Class/Traffic Service ($1000)

TDMA(FIX) SYSTEM
AVAILABILITY=>99.9%

USER CLASS	VOICE	VIDEO CONF.	VIDEO INFO. SERV.	DATA MESS.	DATA COMPUT.	TOTAL USER
LARGE BUSINESS	167.33	181.67	0.00	9.84	14.15	372.99
SMALL BUSINESS	27.76	0.00	0.00	3.43	3.21	34.39
GOV. AGENCIES	245.53	179.86	359.79	16.29	27.94	829.42
MUNICIPALITIES	28.04	0.00	0.00	3.42	2.93	34.38
INSTITUTIONS	66.69	173.71	347.51	9.45	13.50	610.88
HOMES AND CONDOS	178.34	0.00	344.21	0.00	5.35	528.35

THE TOTAL COST PER T1 LINE IS =85985.8
SPACE SEGMENT CONTRIBUTION=54872.4
GROUND NETWORK CONTRIBUTION=18493.4
EARTH STA SEGMENT CONTRIBUTION=12620.0

Table 7.1-9. Unit Service Charges

User Class	Voice $/Call-Hr	Video Conf. $/Conf-Hr.	Video Info. $/Hour	Data Message $/56Kbps-Hr	Data Computer $/9.6Kbps-Hr
Large Business	1.61	87.34	0	1.58	.27
Small Business	1.67	0	0	1.65	.31
Government Agencies	1.55	86.47	172.97	1.57	.27
Municipalities	1.69	0	0	1.64	.28
Institutions	1.60	83.51	167.07	1.51	.26
Homes and Condos	1.71	0	165.49	0	.26

+40 Hour Week (2080 Hours/Year)

Table 7.1-10. SS-TDMA/Fixed Beam System Effect of Change of System Parameters on Total Service Charges

• Space Segment Parameters	
Reduce Beams to 46	+3.7%
Reduce Beams to 32	+13.7%
Increase Beams to 100	+2.6%
• Earth Station	
Reduce Antenna Diameter to 5M	+10.5%
Reduce Capacity to 4T1	+34.9%
Increase Capacity to 26T1	-4.8%
• Ground Network	
Area - High Density Urban	-.6%
Area - Low Density Urban	+7.9%
Use of Coaxial Cable	+4.7%
Use of Fiberoptics	+17.4%
• Eliminate Station Space Diversity and Remain at 99.9% Availability	+1,650%
• Above and Reduce Availability to 99.5%	0%

SS-TDMA/Fixed Beam System 2 - Diversity E Zone: 15 Gbps

If station space diversity technology is not sufficiently developed to permit widespread utilization (or is costly), the SS-TDMA/Fixed Beam described previoulsy, can be modified to eliminate the diversity network in rain zones D and B (C,F) and still maintain competitive costs without reductions of availability. In zone E (only 12 percent of system capacity) diversity is employed (or if not, the availability is reduced in zone E to less than 99.5%). Table 7.1-11 presents a summary of the system characteristics, Table 7.1-12 the annual costs per user facility, Table 7.1-13 the unit service costs and Table 7.1-14 the effect of change of system parameters on total service charges. This system is about 15 percent more costly than the case for diversity in all zones and five percent more costly than the 15 Gbps SS-FDMA system.

Table 7.1-11. SS-TDMA/Fixed Beam System 2 Characteristics

- Fixed Beam
- Diversity E-Zone Only
- Peak aggregate capacity 15,000 Mbps
- 99.9% availability

1. System Description
   - Ground Segment: 750 Earth Stations of 20 Mbps (13T1) Peak Capacity Each
     - Burst Rate - 128 Mbps
     - Antenna Diameter - 7 meters
     - Microwave Radio Networking
     - Station Space Diversity in E-Rain Zone Only
     - Facility Density: Average Urban Area
   - Space Segment: 68 Beam Coverage
     - Payload Weight - 2404 lbs.
     - Payload Power - 8270 watts

2. Installed Costs
   - Total

Space Segment	$ 560.9 million
Earth Station	$ 314 9 million
Ground Network	$ 250.4 million
TOTAL SYSTEM	$1,126.2 million

   - Installed cost of Earth Station - $419,000
   - Installed Network costs Per $333,800 Earth Station (average)

3. Annual Service Charges

- Space Segment	$ 673 million
- Earth Station	$ 186 million
- Ground Network	$ 124 million
TOTAL	$ 983 million

SS-TDMA/Fixed Beam System 3

The System characteristics of the 3 Gbps SS-TDMA/Fixed Beam System 3 are summarized in Table 7.1-15, the total annual charges per facility in Table 7.1-16, the unit service charges in Table 7.1-17 and the effect of change of system parameters on cost in Table 7.1-18. The above system would be optimum if a seven meter antenna would be used (12.6% cost reduction). One significant factor in reducing cost is "fill factor" for the space segment. If during the first year of operation, the space segment would operate at 100% capacity rather than the assumed 10% the service charges would be reduced by 57.4%.

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Table 7.1-12. Total Annual Charges vs. Class/Traffic Service ($1000)
SS-TDMA/Fixed Beam System 2

USER CLASS	VOICE	VIDEO CONF.	VIDEO INFO. SERV.	DATA MESS.	DATA COMPUT.	TOTAL USER
LARGE BUSINESS	198.56	212.33	0.00	11.51	16.53	438.95
SMALL BUSINESS	32.78	0.00	0.00	3.98	3.69	40.45
GOV. AGENCIES	292.79	210.47	421.03	19.07	32.69	976.06
MUNICIPALITIES	33.07	0.00	0.00	3.98	3.41	40.45
INSTITUTIONS	79.18	204.17	408.43	11.11	15.87	718.77
HOMES AND CONDOS	209.86	0.00	405.04	0.00	6.30	621.72

THE TOTAL COST PER T1 LINE IS = 100,954.7

SPACE SEGMENT CONTRIBUTION = 69277.7

GROUND NETWORK CONTRIBUTION = 12,563.

EARTH STA SEGMENT CONTRIBUTION = 19,1148.

\+ INCLUDES AVERAGE FOIL DIVERSITY IN E ZONE AND AVERAGE E.S. COSTS BASED ON RELATIVE CAPACITY

	E	12%
ZONE	D	68%
	B	20%

Table 7.1-13. SS-TDMA/Fixed Beam System 2 Unit Service Charges

User Class	Voice $/Call-Hr	Video Conf. $/Conf-Hr.	Video Info. $/Hour	Data Message $/56Kbps-Hr	Data Computer $/9.6Kbps-Hr
Large Business	1.91	102.08	0	1.84	.32
Small Business	1.97	0	0	1.91	.35
Government Agencies	1.85	101.19	202.42	1.83	.31
Municipalities	1.99	0	0	1.91	.33
Institutions	1.90	98.16	196.36	1.78	.31
Homes and Condos	2.02	0	194.73	0	.30

+40 Hour Week (2080 Hours/Year)

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Table 7.1-14. SS-TDMA/Fixed Beam System 2 - Effect of Change of System Parameters on Total Service Charges

• Space Segment Parameters	
Reduce Beams to 46	+9.3%
Reduce Beams to 32	+24.1%
Increase Beams to 100	-2.8%
• Earth Station	
Reduce Antenna Diameter to 5M	+16.7%
Reduce Antenna Diameter to 3M	+75.9%
Reduce Capacity to 4T1	+41.7%
Increase Capacity to 26T1	-6.5%
• Ground Network	
Area - High Density Urban	-0.9%
Area - Low Density Urban	+6.5%
• Utilizing Diversity in all Zones	-14.8%
• Going to FDMA System with Diversity in all Zones	-4.8%
• Eliminating Diversity (in E Zone) and Reducing E Zone availability to 99.5%. Zones D and B (C,F) have availability of 99.9%	0%
• Reducing Aggregate Peak Capacity to 5 Gbps	+73%

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Table 7.1-15. SS-TDMA/Fixed Beam System 3 Characteristics

- Peak Capacity 3 Gbps
- 99.5% Availability
- Fixed Beam

1. System Description
   - Ground Segment: 150 Earth Stations of 20 Mbps (13T1) Peak Capacity Each
     - Burst Rate - 128 Mbps
     - Earth Station Antenna Diameter - 5 meters
     - Microwave Radio Networking (no diversity)
     - Facility Density: Average Urban Area
   - Space Segment: 32 Beam Coverage
     - Payload Weight - 1027 lbs.
     - Payload Power - 3074 watts

2. Installed Costs
   - Total

Space Segment	$ 298.6 million
Earth Station	$ 53 2 million
Ground Network	$ 53.7 million
TOTAL SYSTEM	$ 405.5 million

   - Installed cost of Earth Station - $354,700
   - Installed Network costs Per $357,830 Earth Station

3. Annual Service Charges

- Space Segment	$ 358.3 million
- Earth Station	$ 31.5 million
- Ground Network	$ 25.3 million
TOTAL	$ 415.1 million

SS-TDMA/Fixed Beam System 4

The system considered here is similar to System 3 except the ground segment consists of a group of standalone earth stations. A summary of the system design and cost characteristics are given in Table 7.1-19, the annual facility costs in Table 7.1-20, the unit service charges in Table 7.1-21 and the effect of change of system parameter in Table 7.1-22. The

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Table 7.1-16. Total Annual Charges Vs. Class/Traffic Service ($1000)
SS-TDMA/Fixed Beam System 3

USER CLASS	VOICE	VIDEO CONF.	VIDEO INFO. SERV.	DATA MESS.	DATA COMPUT.	TOTAL USER
LARGE BUSINESS	403.30	369.41	0.00	11.22	16.27	800.14
SMALL BUSINESS	60.34	0.00	0.00	3.53	3.55	67.43
GOV. AGENCIES	689.96	391.08	782.16	19.81	33.89	1827.5
MUNICIPALITIES	60.96	0.00	0.00	3.46	2.96	67.48
INSTITUTIONS	199.46	415.60	831.21	12.54	18.14	1476.9
HOMES AND CONDOS	548.06	0.00	754.95	0.00	6.63	1309.3

THE TOTAL COST PER T1 LINE IS =214015.
SPACE SEGMENT CONTRIBUTION= 184402.
GROUND SEGMENT CONTRIBUTION= 13468.
EARTH STA SEGMENT CONTRIBUTION= 16145.

Table 7.1-17. Unit Service Charges

User Class	Voice $/Call-Hr	Video Conf. $/Conf-Hr.	Video Info. $/Hour	Data Message $/56Kbps-Hr	Data Computer $/9.6Kbps-Hr
Large Business	5.39	177.60	0	1.80	.31
Small Business	4.83	0	0	1.70	.34
Government Agencies	6.63	187.98	375.97	1.90	.33
Municipalities	4.88	0	0	1.66	.23
Institutions	5.99	199.81	399.62	2.01	.35
Homes and Condos	5.27	0	362.96	0	.32

+40 Hour Week (2080 Hours/Year)

Table 7.1-18. SS-TDMA/Fixed Beam System 3 - Effect of Change of System Parameters on Total Service Charges

• Space Segment Parameters	
Increase Beams to 46	-0.45%
Increase Beams to 68	+6.7%
• Earth Station	
Increase Antenna Diameter to 7M	-12.6%
Reduce Antenna Diameter to 3M	+30.9%
Reduce Capacity to 4T1	+13.5%
Increase Capacity to 26T1	-1.8%
• Ground Network	
Area - High Density Urban	-2.7%
Area - Low Density Urban	+0.9%
Use of Coaxial Cable	+7.2%
Use of Fiberoptics	+6.3%
Increase Availability to 99.9%	+1450%
Go to Standalone System	+16.5%
If Space Segment is Filled to 100% Capacity During Initial Operation	-57.4%

standalone system is more costly because of the use of many non-optimum sized earth stations (1T1 and 4T1) which account for greater costs than the networking costs of the previous case.

SS-TDMA/Fixed Beam System 5

By increasing the capacity from 3 Gbps to 5 Gbps and changing the earth station diameter to seven meters, the space segment cost remains about the same while the overall service costs are significantly reduced. The system characteristics are summarized in Table 7.1-23, the annual facility costs in Table 7.1-24, the unit service costs in Table 7.1-25 and the effect of change of system parameters on cost in Table 7.1-26. A gaine on increase the fill factor of the space segment to 100% during initial operation will reduce service charges by more than 50 percent.

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Table 7.1-19. SS-TDMA/Fixed Beam System 4 Characteristics

- Standalone Earth Stations
- Peak Capacity 3 Gbps
- 99.5% Availability
- Fixed Beam

1. System Description
   - Ground Segment: Number Earth Sttations

Rain Zone	Capacity (NT1) 1T1	4T1	13T1
B (C,F)	116	57	19
D	395	193	66
E	70	34	12

   - Antenna Diameter 5 meters

   - Space Segment: 46 Beam Coverage
   - Payload Weight - 1027 lbs.
   - Payload Power - 3074 watts

2. Installed Costs
   - Total

Space Segment	$ 298.6 million
Earth Station	$ 214 6 million
TOTAL SYSTEM	$ 513.2 million

   - Installed cost ($1000) of Earth Station Capacity (NT1)

Rain Zone	Capacity (NT1) 1T1	4T1	13T1
B (C,F)	146	246.1	292.4
D	188	253.9	305.7
E	223	377.6	517.2

3. Annual Service Charges

- Space Segment	$ 357.5 million
- Earth Station	$ 127 million
TOTAL	$ 484.5 million

SS-TDMA/Fixed Beam System 6

By utilizing standalone earth stations, the annual service costs are significantly increased. A summary of the system characteristics are given in Table 7.1-27, the annual earth station facility costs in Table 7.1-28, the annual total facility costs in Table 7.1-29, the unit service charges in Table 7.1-30 and the effect of system parameter changes on costs in Table 7.1-31.

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Table 7.1-20. SS-TDMA/Fixed Beam System 4 Total Annual Charges Per Facility ($1000)

User	Voice	Video Conf.	Video Info.	Data Message	Data Computer	Total User
Large Business	403.1	410.1	0	14.1	21.0	848.3
Small Business	135.0	0	0	15.7	16.3	167.0
Government Agencies	633.9	389.6	779.2	21.5	36.9	1861.1
Municipalities	138.2	0	0	15.6	13.1	166.9
Institutions	186.0	416.3	832.6	18.7	20.1	1473.7
Private Homes and Condos (1000:1)	538.4	0	777.9	0	7.9	1324.2

The total annual chages per T_1 249.4
Space Segment Contribution 184.0
Earth Station Contribution 65.4

Table 7.1-21. Unit Service Charges

User Class	Voice $/Call-Hr	Video Conf. $/Conf-Hr.	Video Info. $/Hour	Data Message $/56Kbps-Hr	Data Computer $/9.6Kbps-Hr
Large Business	5.38	197.17	0	2.26	.40
Small Business	10.82	0	0	7.55	1.57
Government Agencies	6.09	187.32	374.62	2.07	.35
Municipalities	11.08	0	0	7.50	1.26
Institutions	5.59	200.14	400.29	4.33	.39
Homes and Condos	5.18	0	374.0	0	.38

40 Hour Week (2080 Hours/Year)

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Table 7.1-22. SS-TDMA/Fixed Beam System 4 - Effect of Change of System Parameters on Total Service Charges

• Space Segment Parameters Increase Beams to 68	+6.6%
• Earth Station (D Zone) Increase Antenna Diameter to 7M (4T1 Station) Reduce Antenna Diameter to 3M	 -9.1% +29.7%
• Increase Availability to 99.9%	+1,497%
• Utilize FDMA System Instead of TDMA (Fixed Beam) System	100%
• If Space Segment is Filled to 100% Capacity During Initial Time of Operation	-49.8%

Table 7.1-23. SS-TDMA/Fixed Beam System 5 Characteristics

- Peak Capacity 5 Gbps
- 99.5% Availability
- Fixed Beam

1. System Description
   - Ground Segment: 250 Earth Stations of 20 Mbps (13T1) Peak Capacity Each
     - Burst Rate - 128 Mbps
     - Earth Station Antenna Diameter - 7 meters
     - Microwave Radio Networking (No Diversity)
     - Facility Density: Average Urban Area
   - Space Segment: 46 Beam Coverage
     - Payload Weight - 1066 lbs.
     - Payload Power - 2305 watts

2. Installed Costs
   - Total

Space Segment	$ 298 million
Earth Station	$ 101.8 million
Ground Network	$ 89.5 million
TOTAL SYSTEM	$ 489.3 million

   - Installed Cost of Earth Station - $407,100
   - Installed Network Costs Per Earth Station $357,830

3. Annual Service Charges

- Space Segment	$ 357.6 million
- Earth Station	$ 60.3 million
- Ground Network	$ 43.8 million
TOTAL	$ 461.7 million

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Table 7.1-24. Total Annual Charges Vs. Class/Traffic Service ($1000)
SS-TDMA/Fixed Beam System 5

USER CLASS	VOICE	VIDEO CONF.	VIDEO INFO. SERV.	DATA MESS.	DATA COMPUT.	TOTAL USER
LARGE BUSINESS	275.76	244.79	0.00	7.45	10.78	538.74
SMALL BUSINESS	40.79	0.00	0.00	2.32	2.30	45.41
GOV. AGENCIES	469.17	259.56	519.11	13.16	22.51	1230.0
MUNICIPALITIES	41.16	0.00	0.00	2.28	1.95	45.44
INSTITUTIONS	136.91	278.94	557.89	8.43	12.18	994.36
HOMES AND CONDOS	369.04	0.00	508.34	0.00	4.46	881.70

THE TOTAL COST PER T1 LINE IS =142,409.
SPACE SEGMENT CONTRIBUTION=110412.
GROUND SEGMENT CONTRIBUTION=13,468.
EARTH STA SEGMENT CONTRIBUTION=18.529.

Table 7.1-25. Unit Service Charges

User Class	Voice $/Call-Hr	Video Conf. $/Conf-Hr.	Video Info. $/Hour	Data Message $/56Kbps-Hr	Data Computer $/9.6Kbps-Hr
Large Business	3.68	118.50	0	1.20	.21
Small Business	3.28	0	0	1.12	.23
Government Agencies	4.52	125.59	251.17	1.27	.22
Municipalities	3.31	0	0	1.10	.19
Institutions	4.10	134.55	269.12	1.35	.24
Homes and Condos	3.55	0	245.0	0	.22

40 Hour Week (2080 Hours/Year)

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Table 7.1-26. SS-TDMA/Fixed Beam System 5 - Effect of Change of System Parameters on Total Service Charges

• Space Segment Parameters	
Reduce Beams to 32	+0.7%
Increase Beams to 68	+6.7%
Increase Beams to 100	+20%
• Earth Station	
Reduce Antenna Diameter to 5M	+11.3%
Reduce Capacity to 4T1	+24.7%
Increase Capacity to 26T1	-4.0%
• Ground Network	
Area - High Density Urban	-2.7%
Area - Low Density Urban	+2.7%
Use of Coaxial Cable	+6.6%
Use of Fiberoptics	+7.8%
• Increase Availability to 99.9%	+103%
• Increase Availability to 99.9% and Use Station Space Diversity	+1.1%
• Go to Standalone System	+37.2%
• Increase Availability to 99.9% and Use Station Space Diversity Only in E Rain Zone	+22.5%
• If Space Segment is Filled to 100% Capacity During Initial Operation	-51.1%

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Table 7.1-27. SS-TDMA System Characteristics

- Standalone Earth Stations
- Peak Capacity 5 Gbps
- 99.5% Availability
- Fixed Beam

1. System Description
   - Ground Segment: Number Earth Sttations

Rain Zone	Capacity (NT1) 1T1	4T1	13T1
B (C,F)	194	95	32
D	658	322	110
E	116	56	20

   - Antenna Diameter 5 meters

   - Space Segment: 46 Beam Coverage
     - Payload Weight - 1302 lbs.
     - Payload Power - 3617 watts

2. Installed Costs
   - Total

Space Segment	$ 351.2 million
Earth Station	$ 357 6 million
TOTAL SYSTEM	$ 708.8 million

   - Installed cost ($1000) of Earth Station

Rain Zone	Capacity (NT1) 1T1	4T1	13T1
B (C,F)	146	246.1	292.4
D	188	253.9	305.7
E	223	377.6	517.2

3. Annual Service Charges

- Space Segment	$ 421.4 million
- Earth Station	$ 211.7 million
TOTAL	$ 633.1 million

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Table 7.1-28. Annual Earth Station Costs Per Facility ($1000)

User	Voice	Video Conf.	Video Info.	Data Message	Data Computer	Total User
Large Business (4T1)	62.8	84.3	0	4.5	6.6	158.2
Small Business (1T1)	83.2	0	0	12.5	13.1	108.8
Government Agencies (13T1)	47.0	45.4	90.8	4.1	7.1	194.4
Municipalities (1T1)	85.8	0	0	12.5	10.5	108.8
Institutions (13T1)	18.6	56.1	112.3	3.0	4.4	194.4
Private Homes and Condos (X1000) (13T1)	65.6	0	126.6	0	2.2	194.4

Table 7.1-29. SS-TDMA/Fixed Beam System 6 Total Annual Charges Per Facility ($1000)

User	Voice	Video Conf.	Video Info.	Data Message	Data Computer	Total User
Large Business	303.5	314.8	0	11.5	16.8	646.6
Small Business	119.8	0	0	14.7	15.4	149.9
Government Agencies	462.2	288.9	577.8	16.4	28.2	1310.5
Municipalities	122.9	0	0	14.7	12.4	150.0
Institutions	137.0	310.9	621.8	10.7	15.5	1095.9
Private Homes and Condos	400.0	0	587.3	0	6.3	993.6

The Total Annual Charges per T_1 Capacity	195.5
Space Segment Contribution	130.1
Earth Station Contribution	65.4

Table 7.1-30. Unit Service Charges

User Class	Voice $/Call-Hr	Video Conf. $/Conf-Hr.	Video Info. $/Hour	Data Message $/56Kbps-Hr	Data Computer $/9.6Kbps-Hr
Large Business	4.05	151.35	0	1.84	.32
Small Business	9.60	0	0	7.07	1.48
Government Agencies	4.44	138.90	277.79	1.58	.27
Municipalities	9.85	0	0	7.07	1.19
Institutions	4.12	149.47	298.94	2.48	.30
Homes and Condos	3.85	0	282.36	0	.30

40 Hour Week (2080 Hours/Year)

Table 7.1-31. SS-TDMA/Fixed Beam System 6 - Effect of Change of System Parameters on Total Service Charges

- Space Segment Parameters
  - Increase Beams to 68 — +1.5%
- Earth Station (D Zone)
  - Increase Antenna Diameter to 7M
    - 4T1 Station -6.4%
    - 13T1 Station -11.6%
    - 1T1 Station +6.8%
  - Reduce Antenna Diameter to 3M 4T1 Station — +35.8%
- Increase Availability to 99.9% — +1,233%
- Utilize FDMA System Instead of TDMA (Fixed Beam) System +127%
- If Space Segment is Filled to 100% Capacity During Initial Time of Operation — -45.2%

The system described is not optimum respect to earth station antenna diameter. The minimum cost would occur if the 4T1 and 13T1 earth stations would utilize seven meter diameter antennas and the 1T1 station would utilize a five meter diameter antenna. For these antenna diameters, the service costs would be reduced by more than seven percent.

SS-TDMA/Scanning Beam System 2

The SS-TDMA/Scanning Beam system provides minimum service charges at 3 Gbps when compared to the other systems analyzed. A description of the system characteristics is given in Table 7.1-32, and annual facility costs in Table 7.1-33, the unit service charges in Table 7.1-34 and the effect of system parameter changes on cost in Table 7.1-35. It should be noted that the performance of the scanning beam system is very strongly dependent on number of antenna beams coverage.

Table 7.1-32. SS-TDMA/Scanning Beam System 2 Characteristics

- Scanning Beam System
  3000 Mbps Peak Capacity
- 99.5% Availability

1. System Description
   - Ground Segment: 150 Earth Stations of 20 Mbps (13T1) Peak Capacity Each
     - Burst Rate - 128 Mbps
     - Antenna Diameter 7 meters
     - Microwave Radio Networking (No Diversity)
     - Facility Density: Average Urban Area
   - Space Segment: 68 Beam Coverage
     - Payload Weight - 2670 lbs.
     - Payload Power - 6732 watts

2. Installed Costs
   - Total

Space Segment	$ 236.3 million
Earth Station	$ 68 9 million
Ground Network	$ 53.7 million
TOTAL SYSTEM	$ 358.9 million

   - Installed Cost of Earth Station - $459,600
   - Installed Network Costs Per Earth Station $357,830

3. Annual Service Charges

- Space Segment	$ 283.6 million
- Earth Station	$ 40.8 million
- Ground Network	$ 26.3 million
TOTAL	$ 350.7 million

7.1.3 COMPARISON OF 30/20 GHz SYSTEM WITH DDS INTERCITY SERVICE

A comparison of the systems analyzed in Section 7.1.1 and 7.1.2 with existing DDS Intercity Service can be made with the data in Figure 7.1-40. For the 15 Gbps systems, the breakeven distance when compared to DDS can range between 50 and 100 miles with the fixed beam TDMA system (with ground network diversity) approaching the former figure. The lower capacity systems using ground network have breakeven distances which range between 130 miles and 200 miles. The low capacity systems with standalone earth stations will have breakeven distances at greater than 200 miles.

Table 7.1-33. Total Annual Charges Vs. Class/Traffic Service ($1000)
SS-TDMA/Scanning Beam System 2

USER CLASS	VOICE	VIDEO CONF.	VIDEO INFO. SERV.	DATA MESS.	DATA COMPUT.	TOTAL USER
LARGE BUSINESS	343.34	309.00	0.00	9.39	13.61	675.28
SMALL BUSINESS	51.04	0.00	0.00	2.94	2.94	56.91
GOV. AGENCIES	585.55	327.40	654.81	16.59	28.39	1542.0
MUNICIPALITIES	51.53	0.00	0.00	2.88	2.47	56.96
INSTITUTIONS	170.18	350.12	700.26	10.57	15.28	1246.4
HOMES AND CONDOS	462.55	0.00	637.17	0.00	5.60	1105.1

THE TOTAL COST PER T1 LINE IS =180327.
SPACE SEGMENT CONTRIBUTION=145939.
GROUND SEGMENT CONTRIBUTION=13468.
EARTH STA SEGMENT CONTRIBUTION=20920.

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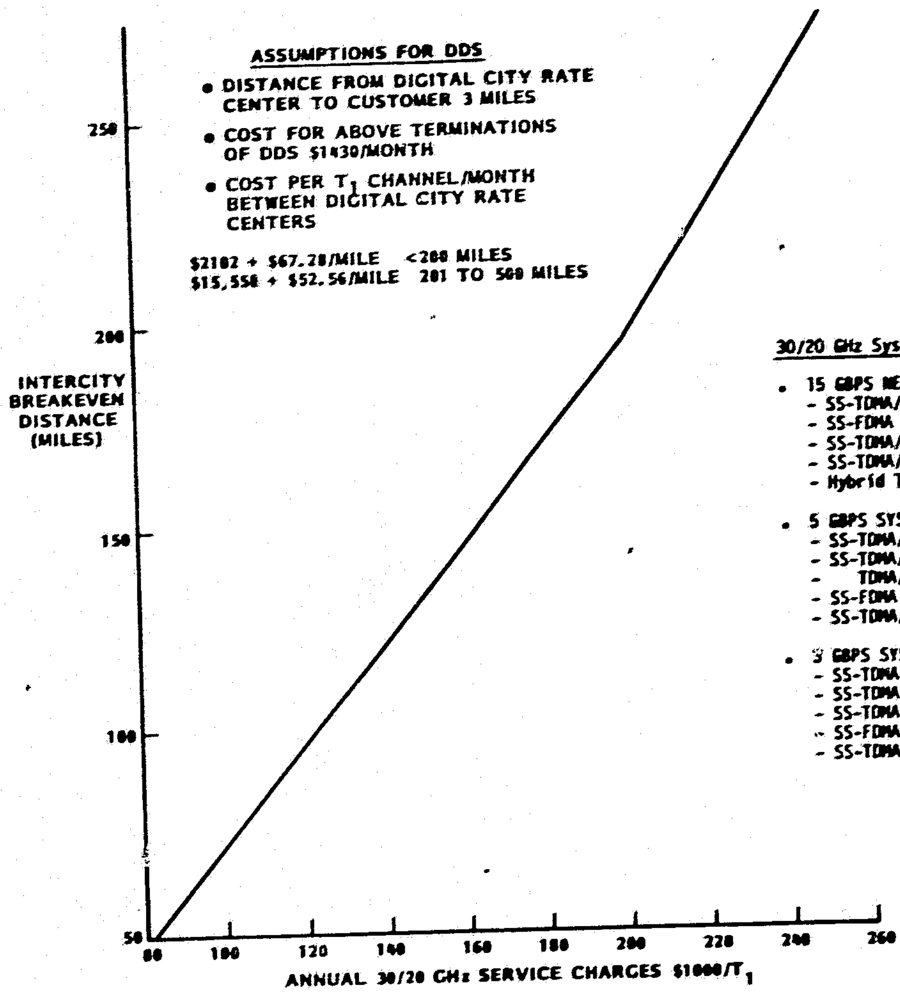
Table 7.1-34. Unit Service Charges

User Class	Voice $/Call-Hr	Video Conf. $/Conf-Hr.	Video Info. $/Hour	Data Message $/56Kbps-Hr	Data Computer $/9.6Kbps-Hr
Large Business	4.59	148.56	0	1.50	.26
Small Business	4.09	0	0	1.41	.28
Government Agencies	5.63	157.40	314.81	1.60	.27
Municipalities	4.13	0	0	1.38	.24
Institutions	5.11	168.33	336.66	1.69	.29
Homes and Condos	4.45	0	306.33	0	.27

40 Hour Week (2080 Hours/Year)

Table 7.1-35. SS-TDMA/Scanning Beam System 2 - Effect of Change of System Parameters on Total Service Charges

• Space Segment Parameters	
Increase Beams to 100	+72.2%
Reduce Beams to 46	+28.3%
• Earth Station	
Reduce Antenna Diameter to 5M	+10.6%
Reduce Capacity to 4T1	+23.3%
Increase Capacity to 26T1	-3.3%
• Ground Network	
Area - High Density Urban	-3.3%
Area - Low Density Urban	+1.7%
Increase Availability to 99.9% and Go to Diversity	+4.4%
Go to TDMA (Fixed Beam) System Under Optimum Design Conditions	+2.8%
If Space Segment is Filled to 100% Capacity During Initial Operation	-54%



CPS SYSTEMS BREAKEVEN DISTANCE WITH DDS

30/20 GHz System	BREAKEVEN DISTANCE (mm)
• 15 GBPS NETWORKED SYSTEMS WITH DIVERSITY (99.9% AVAILABILITY)	
- SS-TDMA/fixed beam	55
- SS-FDMA	63
- SS-TDMA/fixed beam (diversity in rain zone E only)	75
- SS-TDMA/scanning beam	82
- Hybrid TDMA/TDMA	102
• 5 GBPS SYSTEMS (99.5 % AVAILABILITY)	
- SS-TDMA/fixed beam (networked)	102
- SS-TDMA/scanning beam networked	130
- TDMA/FDMA hybrid networked	225
- SS-FDMA networked	258
- SS-TDMA/fixed beam standalone	189
• 3 GBPS SYSTEM (99.5% AVAILABILITY)	
- SS-TDMA (scanning beam) networked	170
- SS-TDMA (fixed beam) networked	178
- SS-TDMA/FDMA hybrid (networked)	320
- SS-FDMA (networked)	410
- SS-TDMA (fixed beam standalone)	272

Figure 7.1-40. Intercity Breakeven Distance vs. Annual 30/20 GHz Servide Charges

SECTION 8

IDENTIFICATION OF CRITICAL TECHNOLOGY

SECTION 8

TASK 7 - IDENTIFICATION OF CRITICAL TECHNOLOGY

8.1 GROUND SEGMENT CRITICAL TECHNOLOGY

8.1.1 IDENTIFICATION OF CRITICAL TECHNOLOGY

Almost without exception, baseband and modulation hardware, required for CPS ground segment implementation, exploit existing technology. Nearly all the technology areas which are potentially critical involve network management functions, such as:

1. Acquisition and synchronization.
2. Transponder management.
3. Demand assignment processing.

These technologies are critical, particularily in the SS-TDMA/Scanning Beam System due to the implementation of the baseband processor, and the software development that is required to manage such a large network. The baseband processor breaks the RF loopback that is conventionally used for earth station acquisition and synchronization. Demand assignment software is in limited use today and will require extensive development for a large scale CPS implementation.

All CPS ground segment baseband and modulation hardware is analogous to hardware now in production, with the exception of the higher rate modulators and demodulators required for the scanning beam and HYBRID payloads. Demand assigned FDMA terminals are in widespread use in the INTELSAT, MARISAT, and other satellite networks. TDMA hardware has been in commercial production for 10 years; TDMA terminals exist at burst rates from 500 kbps to 120 mbps. Today's high rate terminals already employ the bus architecture that will be required for the high rate terminals of the scanning beam payloads. Satellite Switching poses no technology limitations to TDMA terminal development. This is because SS-TDMA is analogous to the transponder hopping technique employed by state-of-the-art wideband TDMA terminals. Both techniques allow an earth station to transmit into and receive several downlinks per TDMA frame. Transponder hopping achieves this through an agile frequency converter. Satellite Switching provides this frequency agility on-board the spacecraft.

Both techniques impact the baseband and modulation hardware only in the fact that several bursts must be transmitted and received per TDMA frame.

Network control can be considered a critical technology for several reasons, including:

1. Acquisition and Synchronization implications of a Baseband Processor.
2. Management and control of 2.5 GHz of spectrum.
3. Demand assignment.

Existing TDMA terminals acquire initial and steady state frame synchronization through RF loopback techniques. These can be closed looped (self monitoring) or open loop (monitoring done by a reference site). This open loop technique must be implemented by the baseband processor, with ranging information (TT&C) playing a large role in initial station entry.

Demand assignment software is finding limited application now, but by all indications is gaining in importance. The software implications of a full scale CPS DAMA implementation are quite significant and will require a large development effort.

Thus it can be seen that network management and control algorithms are the only potentially critical aspects of the CPS ground segment baseband and modulation subsystems.

8.1.2 TECHNOLOGY DEVELOPMENT PLAN FOR 1987 IMPLEMENTATION

Table 8.1-1 is a schedule of Tasks 1 through 4 for the proposed demonstration development program. Items 2 through 4 in the list, Network Engineering, Earth Station Development, and NCC Development are not critical in schedule as long as they are completed before the production phase of the system demonstration.

8.2 SPACE SEGMENT CRITICAL TECHNOLOGY

NASA has under development antennas, narrowband and wideband switches, a baseband processor, traveling wave tube amplifiers, solid state amplifiers and low noise receivers. These are critical technologies that are being addressed and cover most of the technologies needed. In the spacecraft design

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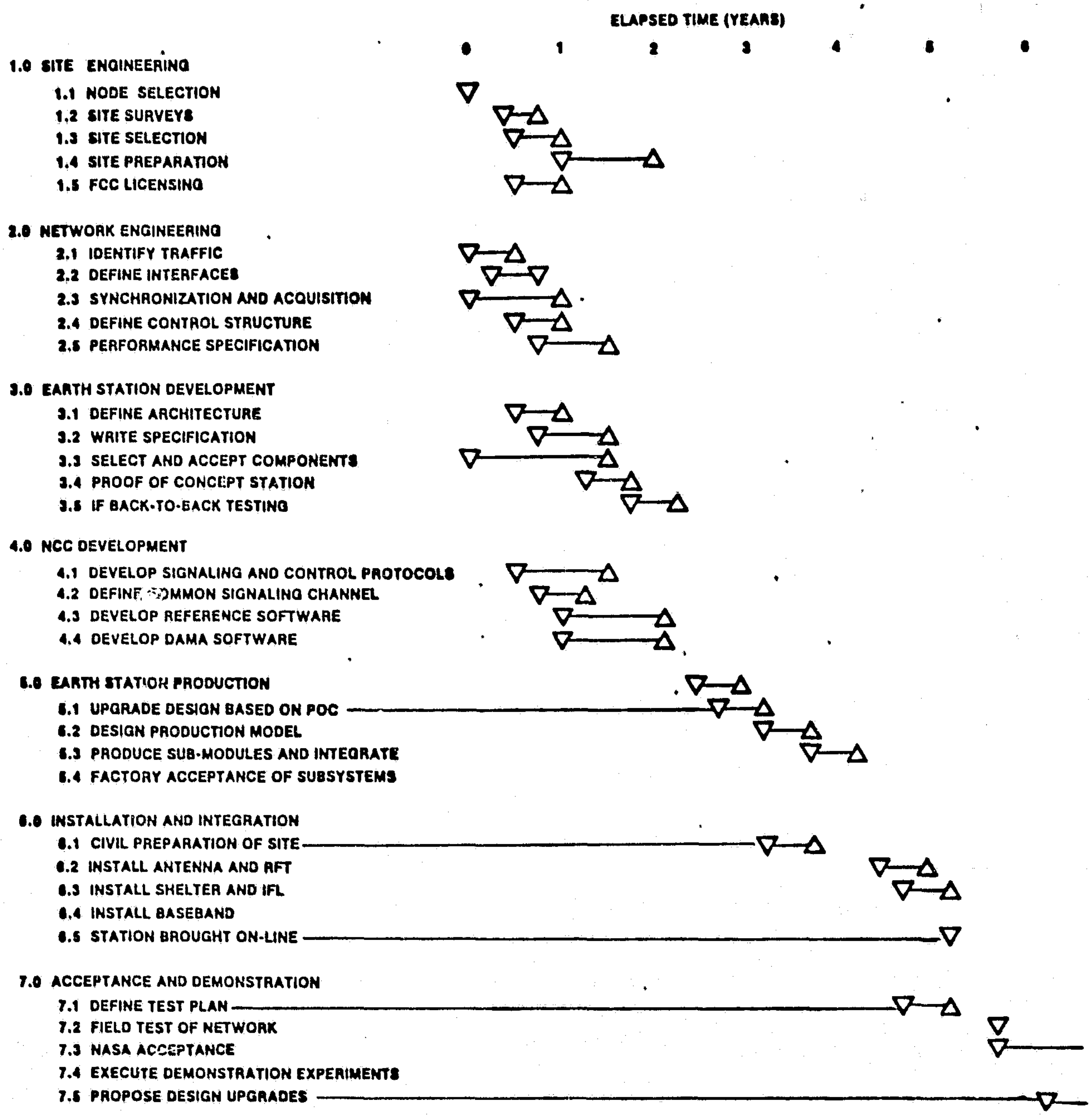
Table 8.1-1. CPS Ground Station Demonstration Development Schedule



two other critical technologies exist, it is assumed that the required IUS for STS launch will be developed. These are antenna pointing control of the two reflector antennas in the face of sun loading and spacecraft attitude control when large solar arrays are used.

In the suggested system design, spacecraft attitude control utilizes a combination of earth sensors and monopulse operation through the reflectors. Monopulse, in addition to providing a lighter weight subsystem than celestial sensors, provides a means of measuring the antenna distortion and potentially provides the basis for compensation.

The large solar arrays are structures having considerable flexibility and low resonant frequencies. Attitude control systems for such structures have not been demonstrated.